MH-53J/M PAVE LOW III/IV SYSTEMS ENGINEERING CASE STUDY

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Foreword

At the direction of the former Secretary of the Air Force, Dr. James G. Roche, the Air Force Institute of Technology (AFIT) established the Air Force Center for Systems Engineering (AF CSE) at its Wright Patterson AFB campus in 2003. With academic oversight by a subcommittee on Systems Engineering (SE), chaired by then-Air Force Chief Scientist Dr. Alex Levis, the AF CSE was tasked to develop case studies of SE implementation during concept definition, acquisition, and sustainment. The committee drafted an initial case outline and learning objectives, and suggested the use of the Friedman-Sage Framework to guide overall analysis.

The Department of Defense is exponentially increasing the acquisition of joint complex systems that deliver needed capabilities demanded by our warfighter. Systems engineering is the technical and technical management process that focuses explicitly on delivering and sustaining robust, high-quality, affordable solutions. The Air Force leadership has collectively stated the need to mature a sound Systems engineering process throughout the Air Force. Gaining an understanding of the past and distilling learning principles that are then shared with others through our formal education and practitioner support are critical to achieving continuous improvement.

The AF CSE has published nine case studies thus far including the A-10, KC-135 Simulator, Global Hawk, C-5A, F-111, Hubble Telescope, Theater Battle Management Core System, International Space Station and Global Positioning System (GPS). All case studies are available on the AF CSE website [http://www.afit.edu/cse]. These cases support academic instruction on SE within military service academies, civilian and military graduate schools, industry continuing education programs, and those practicing SE in the field. Each of the case studies is comprised of elements of success as well as examples of SE decisions that, in hindsight, were not optimal. Both types of elements are useful for learning.

Along with discovering historical facts, we have conducted key interviews with program managers and chief engineers, both within the government and those working for the prime and various subcontractors. From this information, we have concluded that the discipline needed to implement SE and the political and acquisition environment surrounding programs continue to challenge our ability to provide balanced technical solutions. We look forward to your comments on this PAVE LOW case study and our other AF CSE published studies.

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1 Systems Engineering Principles

1.1 General Systems Engineering Process

The Department of Defense continues to develop and acquire joint systems and to deliver needed capabilities to the warfighter. With a constant objective to improve and mature the acquisition process, it continues to pursue new and creative methodologies to purchase these technically complex systems. A sound systems engineering process, focused explicitly on delivering and sustaining robust, high-quality, affordable products that meet the needs of customers and stake holders must continue to evolve and mature. Systems engineering is the technical and technical management process that results in delivered products and systems that exhibit the best balance of cost and performance. The process must operate effectively with desired mission-level capabilities, establish system-level requirements, allocate these down to the lowest level of the design, and ensure validation and verification of performance, meeting cost and schedule constraints. The systems engineering process changes as the program progresses from one phase to the next, as do the tools and procedures. The process also changes over the decades, maturing, expanding, growing, and evolving from the base established during the conduct of past programs. Systems engineering has a long history. Examples can be found demonstrating a systemic application of effective engineering and engineering management, as well as poorly applied, but well-defined processes. Throughout the many decades during which systems engineering has emerged as a discipline, many practices, processes, heuristics, and tools have been developed, documented, and applied.

Several core lifecycle stages have surfaced as consistently and continually challenging during any system program development. First, system development must proceed from a well-developed set of requirements. Second, regardless of the evolutionary acquisition approach, the system requirements must flow down to all subsystems and lower level components. And third, the system requirements need to be stable, balanced and must properly reflect all activities in all intended environments. However, system requirements are not unchangeable. As the system design proceeds, if a requirement or set of requirements is proving excessively expensive to satisfy, the process must rebalance schedule, cost, and performance by changing or modifying the requirement or set of requirements.

Systems engineering includes making key system and design trades early in the process to establish the system architecture. These architectural artifacts can depict any new system, legacy system, modifications thereto, introduction of new technologies, and overall system-level behavior and performance. Modeling and simulation are generally employed to organize and assess architectural alternatives at this introductory stage. System and subsystem design follows the functional architecture. System architectures are modified if the elements are too risky, expensive or time-consuming. Both newer object-oriented analysis and design and classic structured analysis using functional decomposition and information flows/data modeling occurs. Design proceeds logically using key design reviews, tradeoff analysis, and prototyping to reduce any high-risk technology areas.

Important to the efficient decomposition and creation of the functional and physical architectural designs are the management of interfaces and integration of subsystems. This is applied to subsystems within a system, or across large, complex system of systems. Once a solution is planned, analyzed, designed, and constructed, validation and verification take place to

ensure satisfaction of requirements. Definition of test criteria, measures of effectiveness (MOEs), and measures of performance (MOPs), established as part of the requirements process, takes place well before any component/subsystem assembly design and construction occurs.

There are several excellent representations of the systems engineering process presented in the literature. These depictions present the current state of the art in the maturity and evolution of the systems engineering process. One can find systems engineering process definitions, guides, and handbooks from the International Council on Systems Engineering (INCOSE), Electronic Industries Association (EIA), Institute of Electrical and Electronics Engineers (IEEE), and various Department of Defense (DoD) agencies and organizations. They show the process as it should be applied by today's experienced practitioner. One of these processes, long used by the Defense Acquisition University (DAU), is depicted in Figure 1. It should be noted that this model is not accomplished in a single pass. This iterative and nested process gets repeated to the lowest level of definition of the design and its interfaces. Formal models such as these did not appear until after the HH-53H/MH-53J PAVE LOW III program had finished production, but many of the processes were already in practice with both the government and contractor workforces during the time of MH-53M PAVE LOW IV development.

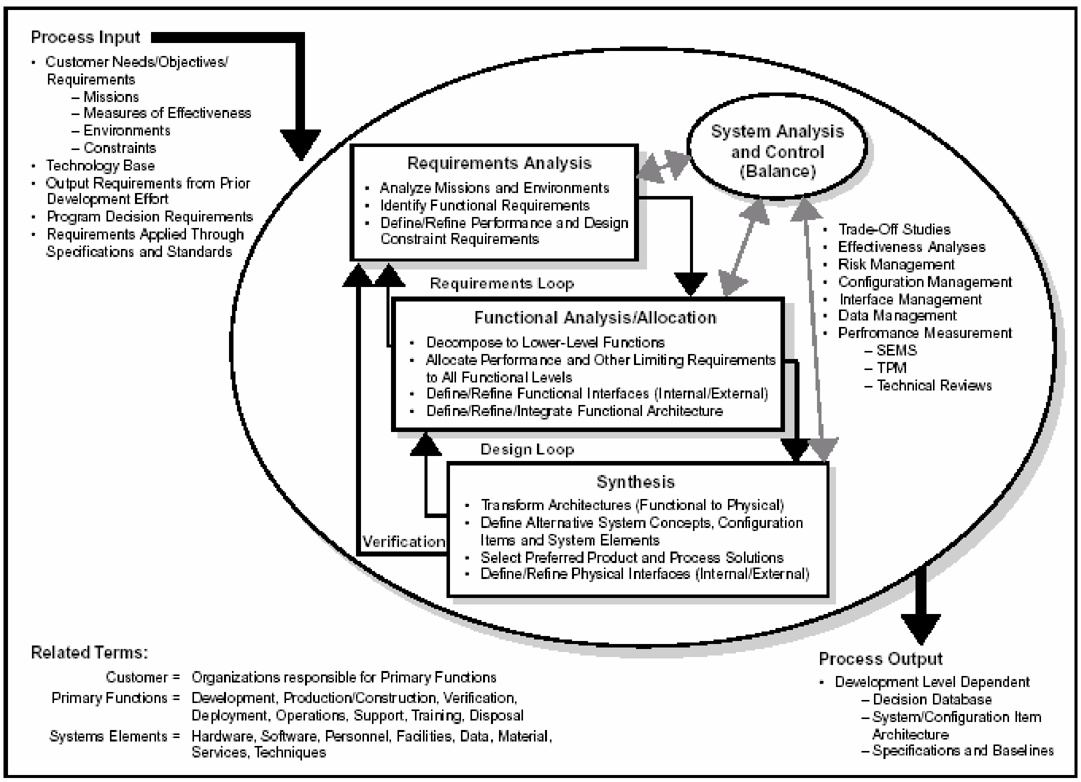

Figure 1. The Systems Engineering Process as Presented by DAU

1.2 DoD Directive 5000 Series

During President Richard Nixon's first term, Secretary of Defense Melvin Laird faced congressional attempts to lower defense spending. The cause was the Vietnam War and the rising cost of defense acquisition, as well as emerging energy and environmental programs. Laird and David Packard, his deputy, recognized the need for a mechanism to control and manage spending especially with the coming fiscal constraint. In May 1969, Packard formed the Defense

Systems Acquisition Review Council (DSARC) to give advice on the acquisition of major weapon systems. It was chartered to review major milestones as well as conduct occasional management reviews. One year later in 1970,[i] Packard issued a policy memorandum that was to become the foundation for the DoD 5000 series of documents[ii] which were first issued in 1971, and as of January 2008 had been reissued 10 times. The original purpose of the DoD 5000 series was to improve the management of acquisition programs and included policy to streamline management, decentralize execution, and use appropriate management structures.[1] The 1971 issue of the DoD 5000 series established the following program considerations (abbreviated here) pertaining to progression of a program through the acquisition process.[2]

1. System need shall be clearly established in operational terms, with appropriate limits, and shall be challenged throughout the acquisition process…Wherever feasible, operational needs shall be satisfied through the use of existing military or commercial hardware…
2. Cost parameters shall be established which consider the cost of acquisition and ownership… Practical tradeoffs shall be made between system capability, cost and schedule…
3. Logistic support shall also be considered as a principle design parameter…
4. Programs shall be structured and resources allocated to assure that the demonstration of actual achievement is the pacing function… Schedules and funding profiles shall be structured to accommodate unforeseen problems and permit task accomplishment without unnecessary overlapping or concurrency.
5. Technical uncertainty shall be continually assessed… Models, mock-ups, and system hardware will be used to the greatest possible extent to increase confidence level.
6. Test and evaluation shall commence as early as possible. A determination of operational suitability, including logistics support requirements, will be made prior to large scale production commitments…
7. Contract type shall be consistent with all program characteristics, including risk…
8. The source selection decision shall take into account the contractor’s capability to develop a necessary defense system on a timely and cost-effective basis…
9. Management information/program control requirements shall provide information which is essential to effective management control… Documentation shall be generated in the minimum amount to satisfy necessary and specific management needs.

1.3 Evolving Systems Engineering Process

The DAU model, like all others, has been documented in the last two decades, and has expanded and developed to reflect a changing environment. Systems are becoming increasingly complex internally and more interconnected externally. The process used to develop the aircraft

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[i] 1970 was also the year that the MAC ROC 19-70 was issued for the requirement for an “integrated system to enable a rescue vehicle to perform search and rescue under conditions of total darkness and/or adverse weather in all geographical areas…” Hence, the Pave Low program was born.

[ii] DoD Directive 5000.1 and its accompanying DoD Instruction 5000.2.

and systems of the past was a process effective at the time. It served the needs of the practitioners and resulted in many successful systems in our inventory. Notwithstanding, the cost and schedule performance of the past programs are fraught with examples of some well-managed programs and ones with less-than-stellar execution. As the nation entered the 1980s and 1990s, large DoD and commercial acquisitions were overrunning costs and behind schedule. Aerospace industry primes were becoming larger and more geographically and culturally distributed and worked diligently to establish common systems engineering practices across their enterprises. However, these common practices must be understood and be useful both within the enterprise and across multiple corporations and vendor companies because of the mega-trend of teaming in large (and some small) programs. It is essential that the systems engineering process affect integration, balance, allocation, and verification and be useful to the entire program team down to the design and interface level.

Today, many factors overshadow new acquisition, including system-of-systems (SoS) context, network-centric warfare and operations, an increased attention to human systems integration, and the rapid growth in information technology. These factors are driving a more sophisticated systems engineering process with more complex and capable features, along with new tools and procedures. One area of increased focus of the systems engineering process is the informational systems architectural definitions used during system analysis. This process, described in the DoD Architectural Framework (DoDAF)[3], emphasizes greater reliance on reusable architectural views describing the system context and concept of operations, interoperability, information and data flows, and network service-oriented characteristics.

1.4 Case Studies

The systems engineering process to be used in today’s complex system and system-of-systems projects is a process matured and founded on principles developed in the past. Examination of systems engineering principles used on programs, both past and present, can provide a wealth of lessons to be used in applying and understanding today’s process. It was this thinking that led to the initiation of the Air Force Center for Systems Engineering case study effort, as well as the present continuation of that effort.

The purpose of developing detailed case studies is to support the teaching of systems engineering principles. They will facilitate learning by emphasizing to the student the long-term consequences of the systems engineering and programmatic decisions on program success. The systems engineering case studies will assist in discussion of both successful and unsuccessful methodologies, processes, principles, tools, and decision material to assess the outcome of alternatives at the program/system level. In addition, the importance of using skills from multiple professions and engineering disciplines and collecting, assessing, and integrating varied functional data will be emphasized. When they are taken together, the student is provided real-world, detailed examples of how the process attempts to balance cost, schedule, and performance.

The utilization and misutilization of systems engineering principles will be highlighted, with special emphasis on the conditions that foster and impede good systems engineering practices. Case studies should be used to illustrate both good and bad examples of acquisition management and learning principles, to include whether:

- every system provides a satisfactory balanced and effective product to a customer;
- effective requirements analysis was applied;
- consistent and rigorous application of systems engineering management standards was applied;
- effective test planning was accomplished;
- there were effective major technical program reviews;
- continuous risk assessments and management was implemented;
- there were reliable cost estimates and policies;
- they used disciplined application of configuration management;
- a well-defined system boundary was defined;
- they used disciplined methodologies for complex systems ;
- human systems integration was accomplished;
- problem solving incorporated understanding of the system within the larger operational environment.

The systems engineering process transforms an operational need into a system or system of systems. Architectural elements of the system are allocated and translated into detailed design requirements. The systems engineering process, from the identification of the need to the development and utilization of the product, must continuously integrate and balance the requirements, cost, and schedule to provide an operationally effective system throughout its life cycle. Systems engineering case studies highlight the various interfaces and communications to achieve this balance, which include:

- The program manager/systems engineering interface between the operational user and developer (acquirer) essential to translate the needs into the performance requirements for the system and subsystems.
- The government/contractor interface essential for the practice of systems engineering to translate and allocate the performance requirements into detailed requirements.
- The developer (acquirer)/user interface within the project, essential for the systems engineering practice of integration and balance.

The systems engineering process must manage risk, both known and unknown, as well as both internal and external. This objective will specifically capture those external factors and the impact of these uncontrollable influences, such as actions of Congress, changes in funding, new instructions/policies, changing stakeholders or user requirements, or contractor and government staffing levels.

1.5 Framework for Analysis

The Air Force Center for Systems Engineering case studies present learning principles specific to each program, but utilize the Friedman-Sage framework[4] to organize the assessment of the application of the systems engineering process. The systems engineering case studies published by the Air Force Institute of Technology (AFIT) employed the Friedman-Sage construct and matrix as the baseline assessment tool to evaluate the conduct of the systems engineering process for the topic program.

The framework and the derived matrix can play an important role in developing case studies in systems engineering and systems management, especially case studies that involve systems acquisition. The Friedman-Sage framework is a nine row by three column matrix shown in Table 2.

Table 1.5-1. A Framework of Key Systems Engineering Concepts and Responsibilities

Concept Domain	**Responsibility Domain**		
	1. Contractor Responsibility	**2. Shared Responsibility**	**3. Government Responsibility**
A. Requirements Definition and Management			
B. Systems Architecting and Conceptual Design			
C. System and Subsystem Detailed Design and Implementation			
D. Systems and Interface Integration			
E. Validation and Verification			
F. Deployment and Post Deployment			
G. Life Cycle Support			
H. Risk Assessment and Management			
I. System and Program Management			

Six of the nine concept domain areas in Table 2 represent phases in the systems engineering lifecycle:

A. Requirements definition and management

B. Systems architecting and conceptual design

C. System and subsystem detailed design and implementation

D. Systems and interface integration

E. Validation and verification

F. Deployment and post deployment

Three of the nine concept areas represent necessary process and systems management support:

G. Life cycle support

H. Risk assessment and management

I. System and program management

While other concepts could have been identified, the Friedman–Sage framework suggests these nine are the most relevant to systems engineering in that they cover the essential life cycle processes in systems acquisition and the systems management support in the conduct of the process. Most other concept areas that were identified during the development of the matrix appear to be subsets of one of these. The three columns of this two-dimensional framework represent the responsibilities and perspectives of government and contractor, and the shared responsibilities between the government and the contractor. In teaching systems engineering in DoD, there has previously been little distinction between duties and responsibilities of the government and industry activities. While the government has responsibility in all 9 concept domains, its primary objective is establishing mission requirements.

Figure 2. Sikorsky MH-53M PAVE LOW IV

2 PAVE LOW System Description

2.1 Background

The Sikorsky HH/MH-53[iii] PAVE LOW series served as long-range Combat Search and Rescue (CSAR) and Special operations helicopters for the United States Air Force. The series consisted of advanced and upgraded models of the HH-53B/C Super Jolly Green Giant, which were derived from the CH-53A Sea Stallion flown by the U.S. Marine Corps. The HH-53B/C was initially developed to supplement the Sikorsky HH-3E Jolly Green Giant in the CSAR role during the Vietnam War. After an extensive modification program to provide night/adverse weather capability, the aircraft was redesignated as the HH-53H PAVE LOW III. Later, after inheriting an additional role as a Special operations platform, it was redesignated the MH-53H. Upgrades in mission and defensive equipment for its expanded role produced the MH-53J PAVE LOW III Enhanced. The last and most advanced variant was the MH-53M PAVE LOW IV. After 29 years of service, the PAVE LOW fleet was retired in September 2008 and was replaced primarily by the Boeing MH-47E Special operations variant of the CH-47 Chinook helicopter flown by the U.S. Army.

Table 2.1-1. *Key PAVE LOW Milestones and Events*

Year	Milestone/Event
15 Mar 67	First flight of newly-designated HH-53B Super Jolly Green Giant; deliveries began in June
03 Apr 67	PACAF identified requirement for a night recovery system in Southeast Asia Operational Requirement (SEAOR) No. 114
14 Sep 67	First two examples of HH-53B arrived in Southeast Asia followed by six more
25 Apr 68	Effort initiated to introduce a night rescue capability on the HH-53B in the form of the Limited Night Recover System (LNRS)
May 68	Contract awarded to Sikorsky Aircraft Corporation for an improved Super Jolly Green Giant, the HH-53C
30 Aug 68	First HH-53C delivered, featuring more powerful engines, additional armor for flight crew, and improved radio communications equipment
23 Oct 68	Development Directive No. 231 authorizes Pave Star program, intended to eliminate shortcomings of LNRS
22 Jun 70	Pave Star cancelled due to cost overruns; Pave Imp program initiated for development of a true Night Recovery System (NRS)
23 Jul 70	MAC ROC 19-70 entitled "Night/Adverse Weather Rescue System" initiated
Jun 72	TF/TA radar installed in an NRS-equipped HH-53B under PAVE LOW I program
20 Jul 72	PAVE LOW II program authorized to determine baseline data for specifications of an operational system to fulfill MAC ROC 19-70

[iii] The MH-53 variants flown by the Air Force are not to be confused with the MH-53E Sea Dragon flown by the U.S. Navy for Airborne Mine Countermeasures. Air Force variants primarily conduct overland missions, while Navy variants serve strictly as maritime platforms.

Year	Milestone/Event
30 Jan 74	PAVE LOW III program initiated by Program Management Directive (PMD); FLIR sensor and INS integrated with TF/TA radar and fitted to YHH-53H for testing
22 Feb 74	Teledyne Systems Company registered an official protest against PL III program office concerning sole-source procurement from a different company
Apr 75	First PL III roll-out scheduled; accident occurred due to faulty wiring
18 Sep 75	Official PL III prototype roll-out ceremony held at WPAFB, OH
Mar 76	Prototype development test and evaluation flight test report issued
29 Apr 77	PMD issued to ASD authorizing procurement and installation of PL III system in eight HH-53C aircraft; NARF at NAS Pensacola, FL awarded PL III modification/installation contract
23 Aug 77	NARF receives first HH-53C for conversion to PL III configuration
Nov 77	PL III subsystem contracts awarded
13 Mar 79	Roll-out ceremony for first operational PL III aircraft held at NAS Pensacola
Apr 79	First production PAVE LOW enters service with Military Airlift Command (MAC) at Kirtland AFB, NM for qualification and acceptance testing
31 Jul 79	PL III drawing baseline declared; production flight test plan approved
11 Jan 80	First real-world rescue mission by operational HH-53H took place 15 nm west of Albuquerque NM
Jan 80	Flight test complete
May 80	PAVE LOW fleet transferred to Tactical Air Command (TAC) in preparation for deployment and rescue of American hostages in Iran
Jul 81	Flight test report issued
Mar 83	PAVE LOW fleet transferred back to MAC
Jun 85	PMD issued to Warner-Robins Air Logistics Center (WR-ALC) to replace two PL IIIs lost in training exercises
Jun 86	WR-ALC accepts program transfer; mission design series designator changed from "HH" to "MH" to reflect the expanded Special operations roles and missions inherited by the PAVE LOW
17 Jul 87	First MH-53J rolled out; externally same--internally upgraded with integrated digital avionics, upgraded radar and night vision systems, improved secure communications, additional titanium armor, provisions for an internally-carried 600 gal fuel bladder, and an uprated transmission
17 Jan 91	Four MH-53J PAVE LOW III helicopters from the 20th Special Operations Squadron led two flights of AH-64A Apaches to make the first strike of the war
1997	MH-53M PAVE LOW IV enhanced threat detection and defense capabilities; modification of 25 aircraft took place in 1999 and 2001
Oct 01	MH-53M aircraft fly long-range Special operations missions into Afghanistan during the first days of Operation Enduring Freedom.
Mar 03	PAVE LOW aircraft once again fly numerous long-range, high-value missions, this time into Iraq as Operation Iraqi Freedom begins
26 Sep 08	Final operational combat mission for the PAVE LOW in support of Operation Iraqi Freedom
17 Oct 08	Formal retirement ceremony held at Hurlburt Field, Florida

2.2 Air Force H-53 Variants[5]

Table 2.2-1 Air Force H-53 Variants

Variant	Mission	Years of Service	Remarks
• **CH-53A Super Jolly Green Giant**	Special Operations	1966 - 1970	Loaned from U.S. Marine Corps; used for covert operations in Laos and North Vietnam
• **CH-53C Super Jolly Green Giant**	Special Operations and heavy-lift	1968 - 1990	Replaced CH-53A for covert operations; later used for heavy-lift operations and training
• **HH-53B Super Jolly Green Giant**	Combat Search and Rescue (CSAR)	1967 – 1990	First operational CSAR variant; fitted with an in-flight refueling probe, external fuel tanks, a rescue hoist, and protective armor
• **HH-53C Super Jolly Green Giant**	CSAR	1968 – 1990	Improved CSAR variant; fitted with additional armor, improved communications gear, and defensive systems
• **YHH-53H Black Knight**	Test Bed	1973 - 1977	Used to test PAVE LOW II/III systems; served as final PAVE LOW III prototype [iv]
• **HH-53H PAVE LOW III**	CSAR	1979 - 1986	First operational PAVE LOW variant
• **MH-53H PAVE LOW III**	CSAR and Special Operations	1986 - 1990	Re-designation to denote added Special Operations role
• **MH-53J PAVE LOW IIIE (Enhanced)**	CSAR and Special Operations	1987 – 2008	Improved variant with integrated digital avionics, an upgraded transmission, more powerful engines, and various enhanced mission and defensive systems
• **MH-53M PAVE LOW IV**	CSAR and Special Operations	1999 - 2008	Upgraded variant with greatly improved threat detection and defensive systems
• **TH-53A**	CSAR and Special Operations Flight Training	1989 - 2008	MH-53J/M training variant (modified U.S. Marine Corps CH-53A)

Note 1: The PAVE LOW I system was tested on an operational HH-53B rather than on a prototype aircraft. The system never reached production or operational service.

Note 2: All Air Force H-53 variants remaining in service after 1990 were converted to the MH-53J PAVE LOW IIIE configuration, some of which were later upgraded to PAVE LOW IV configuration beginning in 1999.

[iv] The Pave Low I system was tested on a standard HH-53B and never saw production or operational service.

2.3 Specifications: MH-53J PAVE LOW III

General characteristics

- **Crew:** 6 (two pilots, two flight engineers and two aerial gunners)
- **Capacity:** 32 personnel (55 in alternate configuration)
- **Length (Fuselage):** 67.2 ft
- **Length (Rotors Turning):** 88.25 ft
- **Height (Overall):** 24.9 ft
- **Main rotor diameter (6 blades):** 72.25 ft
- **Tail rotor diameter (4 blades):** 16 ft
- **Empty weight:** 32,000 lb
- **Max takeoff weight:** 46,000 lb (50,000 lb in wartime)
- **Power plant:** 2× General Electric T64-GE-100 turboshaft, 4,330 shaft horsepower (shp) each

Performance

- **Maximum speed:** 170 knots (196 mph)
- **Cruise speed:** 150 kt (173 mph)
- **Range:** 600 nmi - can be extended with in-flight refueling
- **Service ceiling:** 20,400 ft

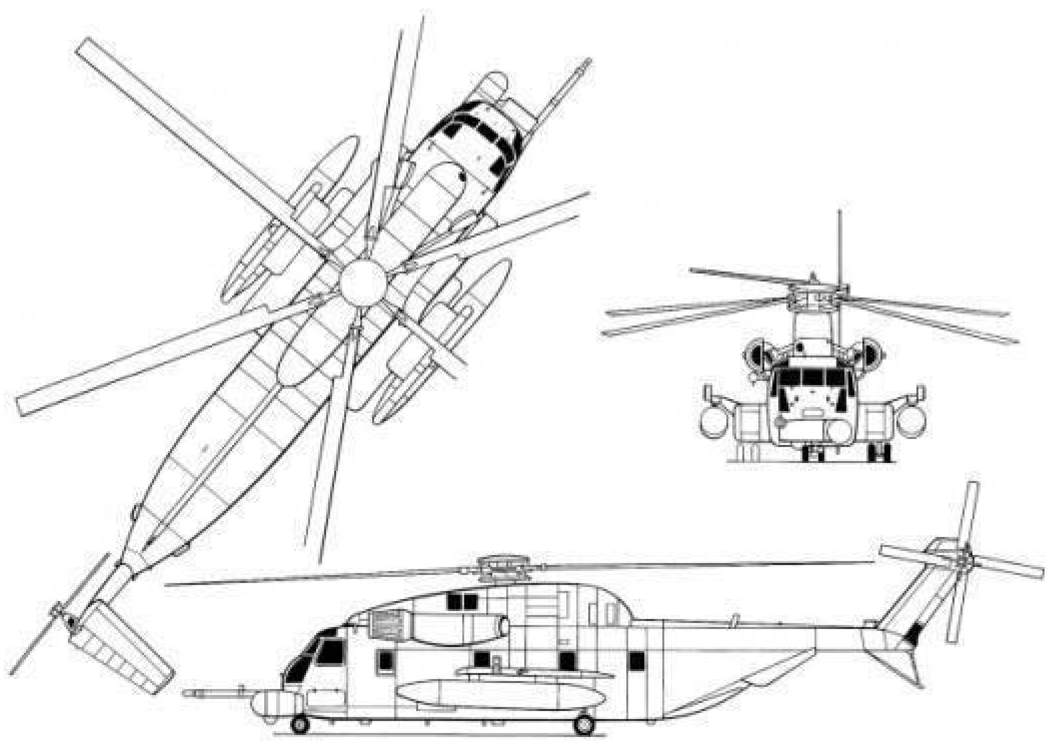

Figure 3. Sikorsky MH-53J PAVE LOW III 3-View Drawing

3 The PAVE LOW Story

By nature, the tactics, techniques, and procedures that define Special operations require the use of highly specialized equipment to execute what are undeniably some of the most daring and hazardous missions in modern warfare. One such example is the Sikorsky MH-53 PAVE LOW, arguably the premier Special operations helicopter in the world. Even in the wake of its withdrawal from service in 2008, the extraordinary performance and unique capabilities it brought to the battlefield remain second to none. To fully appreciate the impressive capabilities embodied by the PAVE LOW, one must understand its heritage, the roots of which began during the U.S. involvement in Vietnam.[6]

3.1 The Challenge of Night Rescue

During the Vietnam War, the use of surface-to-air missiles and anti-aircraft artillery by a very determined enemy resulted in the loss of thousands of U.S. aircraft. Accordingly, Combat Search and Rescue (CSAR) forces incurred a heavy workload in recovering downed American airmen. As the executive agency responsible for CSAR, the Air Force had a need for a dedicated rescue helicopter to supplement the capable but somewhat limited Sikorsky HH-3E Jolly Green Giant.

Recognizing the potential of the CH-53A Sea Stallion heavy-lift helicopter which had entered service with the Marine Corps in September 1966, the Air Force borrowed two Sea Stallions from the Marine Corps to evaluate them for use in the CSAR role. Consideration of this aircraft was primarily based on the power, speed, range and internal payload capacity that it offered. Upon delivery of two Sea Stallions in November and December 1966, Air Force evaluation of the type was carried out at Eglin AFB, Florida. At the conclusion of a favorable evaluation, the first flight of the newly-designated HH-53B Super Jolly Green Giant (usually just shortened to "Super Jolly") was achieved on March 15, 1967, and deliveries to the Air Force began in June. Key features incorporated into the B-model included an extendable in-flight refueling probe, jettisonable auxiliary fuel tanks, a rescue hoist, improved avionics, and defensive armament. The first two examples reached Southeast Asia on September 14, 1967, followed by six more over the next few months.

Figure 4. Marine Corps CH-53A

Figure 5. Air Force HH-53B

Operational use of the HH-53B proved successful, but revealed several areas for improvement which led to the rapid introduction of the HH-53C, the first of which was delivered on August 30, 1968. The C-model made use of more powerful engines, additional armor for the flight crew and improved radio communications gear. This improved model of the Super Jolly Green Giant was rapidly deployed to the Southeast Asia Theater of operations where it proved to be even more effective in CSAR. Still, despite the impressive capabilities that the HH-53B/C

brought to bear, it remained deficient in one major area−the ability to effectively perform the mission at night, especially in adverse weather conditions. The Air Force had actually identified the need for an aircraft capable of performing personnel recovery at night and in all kinds of weather as early as 1965, even before the HH-53 had entered service.

However, other more pressing needs across the military services took precedence and this requirement went largely unaddressed for two years. The inherent risks associated with entering hostile territory by air to recover downed airmen were obvious; attempting to do so at night was borderline suicidal from a flight safety standpoint. Therefore, CSAR operations were typically carried out only in daylight hours. Generally speaking, the only exceptions to this were the precious few occasions when airmen went down in the most benign and relatively risk-free environments in which the chances of enemy contact were slim. Around-the-clock air operations resulted in a number of downed aircraft during the hours of darkness, the crews of which were usually forced to try and evade capture in enemy held territory until a rescue attempt could be mounted at daybreak. Unfortunately, many of them were unsuccessful and ended up being captured or killed while waiting for sunrise.

To further complicate matters, the large array of aircraft needed to successfully carry out and support a rescue mission required extensive planning and coordination among all involved, including the other military services. Careful orchestration by upper command and control elements was necessary to deconflict the sheer volume of aircraft using the same airspace. Furthermore, such missions put an inordinate number of personnel and resources at risk. All of the aforementioned factors, combined with mounting losses of personnel and aircraft as combat intensified, made the requirement for a more effective CSAR platform more urgent, leading it to be spelled out more emphatically in Southeast Asia Operational Requirement (SEAOR) Number 114 dated April 03, 1967. This requirement called for an aircraft capable of penetrating hostile territory with little or no support, independently locating and retrieving the survivor(s), and affecting a safe and rapid egress back to friendly territory, all under the cover of darkness in all kinds of weather. It became time critical that such an aircraft be fielded as quickly as possible. The demonstrated capability and performance of the HH-53B/C in the CSAR arena during daytime made it logical to simply modify these aircraft, rather than attempt to develop and produce a whole new aircraft for the mission.

Figure 6. Early Night Vision Goggles *Figure 7. Infrared view of jeep*

Although the need for an all-aspect air rescue capability had existed for decades, it was only during the years of the Vietnam War that the technology finally came within reach to make nighttime adverse weather rescue operations by air a reality. Night vision technology was still in

its infancy, but it was maturing at a steady pace and becoming more commonplace on the battlefield as the war progressed. Efforts to exploit night vision capability for CSAR resulted in a number of programs, some of which overlapped and ran concurrently as research proceeded at a feverish pace. The first effort to introduce a night rescue capability on the HH-53 was initiated on April 25, 1968, and involved a system known as the Limited Night Recovery System (LNRS). This system was comprised of a Low Light Level Television (LLLTV) camera, an infrared (IR) illuminator, a Direct View Device, a Doppler navigation system, a radar altimeter and an Automatic Approach and Hover Coupler System. Operational testing, which was accomplished at Eglin AFB, consisted of 96 simulated rescue sorties. Tests clearly demonstrated the system did indeed provide a limited capability to accomplish night combat aircrew recoveries over a variety of terrain, and deployment of the system was recommended. Subsequently, incorporation of the LNRS on a number of HH-53s based in Thailand at Udorn Royal Thailand Air Force Base (RTAFB) began in November 1969. Two months later, a total of eight aircraft had received the modification.

Although the LNRS added additional capability to the aircraft, its limitations were recognized early on and it was acknowledged to be an interim solution. Research continued toward fulfilling the goal of full night/adverse weather CSAR capability; only six months after LNRS began, an even more ambitious program was born. Running concurrently with LNRS, the Pave Star program had been authorized on October 23, 1968, and initiated on December 16 that year. Its goal was to provide a worldwide, all-weather rescue capability which effectively eliminated the shortcomings associated with LNRS. However, severe cost overruns resulted in the cancellation of Pave Star barely eighteen months after it began. As a result, a reduced program dubbed Pave Imp was initiated on June 22, 1970. It was intended to make use of improvements derived from the short-lived Pave Star program and incorporate them into a Night Recovery System (NRS) for the HH-53B/C, hopefully attaining the goals originally set for Pave Star.

Tests were conducted in 1971 using a modified HH-53C to verify that performance of the Pave Imp system was at least equal to or better than that of the LNRS. Results were positive and combat evaluation was subsequently accomplished at Udorn RTAFB during a 90-day period.

Although Pave Imp provided a significant increase to existing night recovery capabilities and it was recommended that the system continued to be utilized to the fullest extent possible, the team responsible for evaluating the system made it clear limitations still existed. They concluded efforts should continue toward developing an unrestricted all-weather night rescue system.

Barely one month after efforts had begun to establish effective night vision capability through Pave Imp, a Required Operational Capability (ROC), designated ROC 19-70 Night/Adverse Weather Rescue System, was established on July 23, 1970 (Appendix C). As a result of this, direction was given in November of that year to evaluate the use of a Forward Looking Radar (FLR) to provide low-level penetration capability for the HH-53. The FLR would work in concert with night vision systems to provide CSAR capability in total darkness under adverse weather conditions in all geographical areas at low level. This program, christened PAVE LOW, marked the beginning of a revolution in night/adverse weather CSAR capability, ultimately leading to what would become the pinnacle of combat rescue platforms.

3.2 The Rise of the PAVE LOW

The need for low-level penetration while performing the CSAR mission was self-evident. However, it became obvious sole reliance on night vision to perform the task within acceptable flight safety margins was impractical, particularly given the heavy pilot workload, mental stress, and crew fatigue associated with such demanding flying. The PAVE LOW program aimed to integrate an FLR, more specifically Terrain-Following/Terrain Avoidance (TF/TA) radar, into the HH-53. This, in concert with night vision systems developed under Pave Imp, would be used to attain the desired capabilities. Practical testing and use of the two systems would prove their codependence upon the other; eventually, the two requirements would be merged, along with other features, into a single package. The initial test concept involved installation of a Norden AN/APQ-141 TF/TA radar system, which was under development for the Army's ongoing Lockheed AH-56 Cheyenne attack helicopter program.

Figure 9. Lockheed AH-56ACheyenne

Figure 8. YHH-53H Black Knight

Sikorsky installed the radar, which was modified to provide manual TF/TA steering data to the pilot, in an NRS-equipped HH-53B in June 1972 and evaluation was completed six months later. Results were very encouraging, but since the radar was merely a flight test example versus a production-ready model, further development costs and program risks to bring this particular system up to production standards were ultimately deemed too high, so the AN/APQ-141 was eliminated from consideration in favor of one already in production. Even before evaluation of the TF/TA radar was completed under the original PAVE LOW program – now referred to as PAVE LOW I to differentiate between it and the next iteration of the program – PAVE LOW II (PL II) was proposed on July 20, 1972. It was envisioned as a developmental/production/ modification program which aimed to address three distinct limitations identified in previous programs: inability to avoid terrain and exposure to hostile radar/sensor-directed threats at low level; insufficient accuracy in the navigation system to reach the rescue area at low level; and inability to precisely locate the survivor(s) and hold a hover over his/her position. Again using a modified HH-53B, these deficiencies were addressed through the installation of a variety of systems including: a new self-contained navigation system known as a Heading Reference System using Doppler technology; a Projected Map Display System (PMDS); Flight Director Instruments; an Electronic Location Finder (ELF); and a Hover Coupler (HC). Research and Development (R&D) efforts in PL II were initiated to determine baseline data for specifications of an operational system. The number of modifications made to the aircraft warranted a new designation and the test aircraft became the YHH-53H, with the "Y" prefix to be dropped on the eventual operational model. The flight test and evaluation program, which took place in 1973 at

Edwards AFB, California, demonstrated a significant increase in the ability to perform night rescue. More specifically, it confirmed the feasibility of integrating all primary systems with the existing Automatic Flight Control System (AFCS) to maintain a hover over personnel equipped with a survival radio. Although deficiencies were found, evaluators were favorably impressed and development of a full prototype night rescue system based on those tested under PL II was recommended. By this time, American forces were being withdrawn from Vietnam, but the night/adverse weather CSAR requirement remained relevant.

3.3 PAVE LOW II and III – Development of an In-House Prototype

Even before testing and evaluation of the YHH-53H had begun, the Directorate of Combat Systems (under which the PL II program and all other aircraft weapon systems were ultimately managed) submitted a development plan in August 1972 which encompassed a total expenditure of $14.2M for the modification of eight NRS-equipped helicopters to PL II configuration. These costs were based upon the predicted performance of the system, despite the fact it had not yet been flown and evaluated as an integrated system. However, program costs had risen substantially. After completion of the flight test and evaluation program, cost estimates had escalated to more than $20M, at which the Chief of Staff of the Air Force, General David C. Jones, asked, “Can we do it cheaper?” The gunship SPO at the Aeronautical Systems Division, Wright-Patterson AFB, which had just completed a successful in-house gunship program, stated they could develop the system using in-house expertise and off-the-shelf equipment for $3.2M. Under this revised plan, the next phase in development, dubbed PAVE LOW III (PL III), was initiated by a PMD on January 30, 1974 (Appendix D).

The AF gave the SPO the nod to transition to PL III development in-house in late 1973 and the PMD was initiated on January 30, 1974. The modification of the PL II prototype to PL III configuration was begun the following month. The PL III program was modeled heavily on the AC-130 gunship program. Seven gunships had been modified and sent to Vietnam with measured success. The gunship program demonstrated that an in-house mod program could work. The gunship program was winding down in 1973 when its Director, Colonel Ronald W. Terry, believed his staff could also develop the prototype PAVE LOW helicopter. “It is doubtful that the PL III program could have been accomplished with any other group of Aeronautical Systems Division personnel except those that had been in the gunship SPO.” Working closely with HQ MAC, the PL SPO integrated the TF/TA radar, Inertial Navigation System (INS), computers, signal generators, map displays, and Attitude Direction Indicators (ADI) into a prototype helicopter, the YHH-53H. As a result of the successful evaluation of the PL III, a revised PMD was issued April 29, 1977, authorizing procurement and installation of the PL III system in eight HH-53Cs. Approval was also given to modify the prototype to production standards, making a total of nine HH-53H aircraft. All structural modifications and installation of subsystems and components were carried out at the Naval Air Rework Facility (NARF), Naval Air Station (NAS) Pensacola, Florida. This was done to mitigate costs and risks in regard to technical and logistics support.

The concept of prototyping is not new to systems engineering. However, there are mixed feelings about prototyping throughout the DoD. (A-10 CS p.4) In particular, these mixed views center around prototyping in the competitive phase prior to full-scale development. Competitive prototyping can help mitigate technical and life cycle cost risk by delaying costly commitment decisions for full-scale development until after the basic design has been demonstrated and cost estimates have matured. (A-10 CS p.4) The Air Force has had prototype "fly-offs" in previous developments (e.g., the A-X program, the Lightweight Fighter [LWF] program, and the Advanced Tactical Fighter [ATF] program to name a few). The typical downside of this approach is that development costs rise and schedules lengthen. In the case of the PL III, however, because the development costs were so high and the Chief of Staff of the Air Force asked if it could be done cheaper (or else cancel the effort), the Air Force decided to take on the risk of the cost of development based on a similar successful program (the AC-130 gunship). Also, in the case of the PL III, and later the PL IV, effective prototyping was accomplished at the subsystem and component level.

Figure 10. General Dynamics YF-16 and Northrop YF-17 Lightweight Fighter prototypes

One problem recognized by the PL III SPO managers during the development of PL III was the lack of mission-oriented operational experience within the SPO. The same problem had been encountered during the AC-130 gunship program. The difficulty was much more noticeable in the PL program as no Air Force officer in the SPO had experience flying helicopters or any familiarity with the technology needed to perform a rescue mission. The SPO managers discussed this problem with the customer, MAC. The SPO wanted someone who would have adequate rank to be able to effect changes if required within the SPO, and to be able to discuss problems with decision makers at the HQ MAC level. He needed experience in staff work as well as an understanding of engineering. He also needed experience in rescue during the Vietnam War and qualifications as an HH-53 pilot. To meet the needs of the SPO, MAC assigned Lt Col Frank J. Pehr to Wright-Patterson AFB. Lt Col Pehr, who had years of experience in HH-53 helicopters and who had been on rescue missions in combat, was very much an advocate of the PL mission. He assisted in designing the prototype, piloting the aircraft during flight tests, and evaluating its operational usability. He was also involved in the production decisions, flew the aircraft during production flight tests, accepted the aircraft for MAC, became the PL III Training Squadron Commander, and even went on temporary duty to the Tactical Air Command (TAC) when the aircraft were transferred. "He knew more about the PL III system than any other operational pilot in the Air Force."[1]

The gunship program was winding down in 1973 and its Director, Colonel Terry, believed his staff could also develop the prototype PL helicopter. The gunship program used USAF personnel bearing the integrating responsibility for fielding gunship aircraft. This type of

effort had not been accomplished at WPAFB since World War II and it was extremely high risk. The gunship SPO was organized slightly differently from the normal ASD SPOs at that time. The major differences were in the personnel and their responsibilities. There were four groups of "specialists." Colonel Terry had a staff of one civilian, one military officer, and a secretary. There was a test organization of approximately four people who were in charge of flight testing. There was also a large procurement section and a large engineering section. There were no stand-alone "managers." The engineers actually worked as engineering managers and were responsible for the subsystems and for the logistics problems associated with the subsystems. These gunship personnel and the model SPO developed by Colonel Terry transitioned to the PAVE LOW program in late 1973.

The ability to acquire personnel who possess the desired experience and skill sets needed in the new program can reduce the learning curve and increase the efficiency of the program office. This was the experience of the newly-formed PAVE LOW SPO at WPAFB as gunship personnel were able to transition to the PAVE LOW program and bring with them the skill sets needed to accomplish an in-house weapon system development. Also, the addition of a team member from the user, MAC, early in the program, ensured customer involvement throughout the life of the program. This enhanced the usability of the PAVE LOWs for the aircrew.

The PL III program added additional equipment to the PL II. Along with the equipment installed under PL II, an AN/AAQ-10 Forward Looking Infrared (FLIR) sensor and an Inertial Navigation System (INS) were added to the YHH-53H. The FLIR was selected to replace the previous LLLTV due to lower costs, smaller size and superior performance. In addition, a new TF/TA radar system was chosen. In order to perform the rescue mission in a combat environment, at night, and under adverse weather conditions as described by the MAC ROC, one of the most important contributing subsystems was the multimode radar (Gambone, 1988).[1] During the early planning of the PL III prototype, all DoD radars were thoroughly investigated. The only system that could fulfill the mission requirements was the Texas Instruments - manufactured AN/APQ-126, a multimode TF/TA radar system developed in the early 1970s for use in the LTV A-7D/E Corsair II fixed-wing attack aircraft, flown by both the Air Force and the Navy respectively.

Figure 11. LTV A-7E Corsair II (Navy variant)

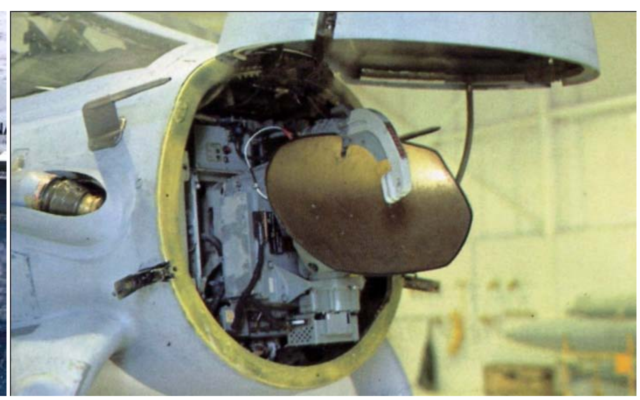

Figure 12. AN/APQ-126 TF/TA radar

This radar performed all of the basic functions which were required for the PL III, particularly TF/TA and ground mapping. The radar, however, was designed to operate in the A-7 and to perform its functions within the A-7's operational high-speed flight envelope. This performance envelope was, of course, significantly different than that of the HH-53. This caused

some difficulties for PL III. The PL III needed to have the capability of flying its mission at a minimum altitude of 200 feet above ground level (AGL). However, the true combat rescue mission requirements called for the aircraft to fly safely at 100 feet AGL. Since this 100-foot altitude would be flown in the TF/TA mode, the radar was the primary subsystem to make this effort successful. In looking at how the A-7s used the radar, it was found that pilots seldom used the TF/TA mode at all. In addition, when they did use the TF/TA mode, they did not fly below 500 feet AGL. Texas Instruments was reluctant to certify the use of a modified AN/APQ-126 at 100 feet AGL. After some simulations of low-altitude approaches to mountains and other terrain features, Texas Instruments agreed to modify the radar to fulfill the 100-foot requirement. The modified version of this system, which became the AN/APQ-158, equipped the PAVE LOW during its entire service life. The AN/APQ-158 was the only major system to have an organic depot, namely the NARF at Jacksonville, FL (Appendix E). The digital computer, FLIR, Doppler radar and Symbol Generator systems were repaired at the manufacturer's facilities. (Gambone, 1988)[1]

All of the specialized mission systems in the PAVE LOW were collectively integrated through a central avionics computer. System design, integration and modification were all accomplished using "in-house" Air Force personnel, funding and facilities, coupled with off-the-shelf subsystems to reduce total acquisition costs. Sixteen months after the program began, the newly modified aircraft made its First Flight under the PL III program in May 1975. In order to determine the effectiveness of the systems installed, the YHH- 53H was tested extensively under a combined Development Test & Evaluation (DT&E) / Initial Operational Test & Evaluation (IOT&E) program from June 9, 1975 through September 30, 1977. During this time, the test program was interrupted briefly to accommodate a formal roll-out ceremony on September 18, 1975, at Wright-Patterson AFB, Ohio, home of the Aeronautical Systems Division (ASD) which oversaw the PAVE LOW program. A crucial aspect of the evaluation involved testing in a number of environments with experienced operational flight crews under realistic mission profiles. One of the locations selected for this was Kirtland AFB, New Mexico. During testing there, one crew was unexpectedly afforded an opportunity for a real-world rescue when they heard radio traffic regarding the crash of an HH-3 in a canyon located south of the base. Departing the test range, they used their on-board systems to race to the area and locate the downed helicopter and its crew within ten minutes.

Figure 13. Nighttime view of Pave Low

At the conclusion of the evaluation, not only were all major objectives accomplished, but the final results were very impressive. All crewmembers who participated in the evaluation indicated unequivocally that the PL III system provided the first true capability to accomplish the CSAR mission under conditions of total darkness and marginal weather. Recommendations for improvement were made, however, regarding the equipment used to pinpoint and positively identify the survivor(s) on the ground. Nevertheless, the system had demonstrated an unprecedented

ability to accomplish what had been virtually impossible less than a decade earlier. As a result of the successful evaluation of the PL III, a revised PMD was issued on April 29, 1977, (Appendix F) authorizing procurement and installation of the PL III system in eight HH-53C aircraft. Approval was also given to modify the prototype to production configuration, making a total of 9 HH-53H aircraft.

An RFP was sent out and contractors placed bids on the production program. However, the winner's bid, submitted by Sikorsky Aircraft, far exceeded the budget. The Naval Air Rework Facility (NARF) at Naval Air Station (NAS) Pensacola, Florida submitted a competitor proposal. Shortly thereafter, PL SPO personnel visited the NARF and met with Navy personnel. It was decided that the NARF could perform the PL III modifications and all structural modifications and installation of subsystems were carried out at the facility. This was done to reduce costs and risks in regard to technical and logistics support since all major overhauls and depot maintenance on H-53 helicopters throughout the military services were already being performed there. There were several advantages to this arrangement. Since the NARF was a DoD activity, the PL III SPO did not have to participate in the usual contractual exercises so that the effort was significantly reduced in scope. Unlike many Government-contractor joint efforts, the relationship between the SPO and the NARF was very cordial and non-adversarial. The NARF personnel were expert craftsmen in the fabrication and installation of aircraft parts. If any activity was left out of the contract, it was never a major problem to get the work done. (Gambone, 1988)[1]

Figure 14. Head-on view of HH-53H Pave Low III

The NARF received its first HH-53C for conversion on August 23, 1977. Nineteen months later, on March 13, 1979, a formal ceremony was held at NAS Pensacola during which the first operational PL III helicopter was rolled out in front of an enthusiastic crowd of distinguished military and civilian personnel. At the time, the aircraft had been given the unofficial moniker "Black Knight," a name coined by personnel in the Specialized System Program Office at ASD which managed the PAVE LOW program. They had picked it as a reference to their legacy of work in years past on other nighttime-oriented military aircraft, such as the Lockheed AC-130 Spectre fixed-wing gunship. Additionally, the original test aircraft for PL II and III, wearing an overall flat black paint scheme, had been adorned with an emblem consisting of a chess knight centered within a white circle. However, the Air Force never adopted the name or the symbol, nor did it ever bestow an official nickname upon the aircraft. Although the PAVE LOW name technically referred to the specialized systems installed on-board the HH-53, the term soon became synonymous with the aircraft itself. As modification of each airframe was completed, the helicopters were delivered to Military Airlift Command (MAC) for qualification and acceptance testing, beginning in April 1979. From there, the PL III entered service at Kirtland AFB. The total number of HH-53H PAVE LOWs to enter service was eleven, nine of which were converted from a mix of HH-53B/Cs, and additional rebuilt CH-53Cs.

While at Kirtland, the first real world rescue mission to be flown by an operational HH-53H took place on January 11, 1980, approximately 15 nm west of Albuquerque. The successful response to a privately-owned light aircraft which crashed in adverse weather at night marked the first use of an operational PL III helicopter. Although this mission took place in peacetime, the potential for a combat mission surfaced only a few months later. World events made the mission assignment to MAC short-lived, as the ongoing Iran hostage crisis prompted the Air Force to transfer all PL III aircraft and resources to Tactical Air Command (TAC) in May 1980 and move all PL helicopters to Hurlburt Field, FL. After the failed attempt to rescue the hostages only a month earlier under Operation Eagle Claw, leaders had considered use of the PL III in a second rescue attempt. However, a second attempt proved unnecessary as the hostages were released before a second operation could be implemented. Nevertheless, the functionality of the PAVE LOW system had been proven and the Air Force had finally attained a much-needed capability.

3.4 Expanding Missions and Capabilities

Consideration of the PAVE LOW for rescuing the American citizens held captive in Iran highlighted a new role for which the aircraft was ideally suited. The ability of the PAVE LOW to covertly penetrate hostile territory at high-speed, low-level, and long range had natural applications in support of Special Operations Forces. Recognizing this, the decision was made to expand the HH-53 mission to include infiltration/exfiltration and resupply of friendly forces deep within enemy-held territory. The PAVE LOW offered a degree of flexibility to the Special operations mission which was unmatched by fixed-wing aircraft. Its ability to take off and land virtually anywhere provided tacticians and planners a number of options which were previously unavailable. In essence, the PAVE LOW would become a true Special operations asset, extending well beyond the original CSAR mission requirement developed nearly two decades before. Accordingly, the mission design series designator was changed in 1986 from “HH” to “MH” to reflect the expanded roles and missions inherited by the PAVE LOW. The increased emphasis on Special operations justified further upgrades in mission equipment, which were initiated under the Constant Green program that same year. In the meantime, the MH-53H became fully immersed in the shadowy world of Special operations, leading it to become the first Air Force helicopter to be fully cleared for operation with Night Vision Goggles (NVGs). As each MH-53H underwent modification, it emerged as an MH-53J PAVE LOW III Enhanced. Externally, the MH-53J was almost indistinguishable from the H-model, as most of the changes were internal. Features introduced with the J-model included integrated digital avionics, upgraded radar and night vision systems, improved secure communications, additional titanium armor, provisions for an internally-carried 600 gal fuel bladder, and an uprated transmission. In addition, more powerful engines were introduced in the form of 4,330 shp General Electric T64-GE-100 turboshaft engines (replacing the 3,936 shp T64-GE-7A previously used). The first MH-53J was rolled out on July 17, 1987 at the Naval Aviation Depot (formerly NARF) at NAS Pensacola, achieving Full Operational Capability (FOC) at Hurlburt Field, Florida in 1988.

3.4.1 The Importance of Good Configuration Control

Figure 15. MH-53J inserts Special Operations Forces

In 1987, it became obvious the configuration control for the PAVE LOW production program was a failure and something needed to be done. The Air Force was trying to upgrade five aircraft through the NARF simultaneously. The HH-53Bs, Cs, and Hs, 41 aircraft in total had 12 different configurations going into the NARF depot. Initially, it was discovered there were poor or no records on the current configuration of each aircraft undergoing modification. In order to ensure some level of configuration control, it was decided to do an audit of each aircraft first. The NARF was trying to do commodity modifications on aircraft that were all different. ARINC was hired to perform configuration control. ARINC developed a system for tracking each PAVE LOW by tail number and documented the modifications to each aircraft as they passed through the depot. ARINC developed a "waterfall" flowchart for configuration control of all modifications to the aircraft. This greatly streamlined the process and saved the program time, reduced risk, and cost.

Training for PAVE LOW pilots and aircrew members was accomplished using a fleet of five TH-53As, all of which were converted Sea Stallions acquired from the Marine Corps in 1989. By 1990, all remaining MH-53Hs had been upgraded to MH-53J standard, with an additional thirty-one examples being added to the inventory by way of converted HH-53Bs, HH-53Cs, and CH-53Cs. That same year, in a move designed to better align the MH-53J with its new multifaceted mission, all PAVE LOWs were transferred to the newly-formed Air Force Special Operations Command (AFSOC).

3.5 Suited to the Task

The basic design of the H-53 proved more than adequate for adaptation to the CSAR and Special operations missions. The twin T64-GE-100 engines provided an abundance of power to the 72.25 ft diameter six-bladed main rotor and the 16 ft diameter four-bladed tail rotor. In addition, the dual engine arrangement provided an added margin of safety over single-engine designs. The spacious cabin could accommodate up to 32 personnel or a variety of cargo, depending on the mission, while the hydraulically operated rear ramp made onloading and offloading of cargo, equipment and personnel a quick and easy task. The retractable tricycle landing gear configuration facilitated easy taxiing and ground handling. Large cambered sponsons on either side of the lower fuselage housed additional internal fuel. These sponsons were fitted with cantilever fairings known as “gull wings,” which served as attachment points for externally mounted 650 gal auxiliary fuel tanks, collectively providing an unrefueled range of about 600 nm. If necessary, the range and endurance could be extended even further by use of an extendable in-flight refueling probe fitted on the starboard side of the nose. An automatic hydraulically-actuated blade-folding system for the main rotor and a folding tail pylon, both of which were retrofitted beginning in the early 1990s, facilitated stowage and handling when transporting the PAVE LOW aboard a Lockheed C-5 Galaxy or Boeing C-17 Globemaster III.

Figure 17. Nose-mounted sensor package

Figure 16. MH-53 being loaded onto a C-5B Galaxy

Despite its large size, the PAVE LOW was incredibly fast and maneuverable, with a top speed of 170 kt. Its ability to perform nap-of-the-earth (NOE) flight in rolling and mountainous terrain, day or night, in any weather, was made possible not only by its advanced sensor suite, but also by its inherent agility. Pilots would typically fly as low as 50 ft over the highest obstacle in order to avoid detection on radar and to minimize exposure of the aircraft to enemy air defenses, a technique known as terrain masking. Despite a gross weight of up to 50,000 lb, the PAVE LOW’s robust construction and more-than-adequate power margins allowed pilots to enjoy a virtually unrestricted flight profile. In addition to aggressive low-level flying tactics, a variety of on-board equipment and systems served to protect the PAVE LOW from the inevitable dangers lurking in hostile territory. To defend against threats at the objective, any combination of

Figure 18. MH-53J maneuvers at low-level, high speed

three GAU-2B/A 7.62 mm miniguns or GAU-18/A .50 cal machine guns were mounted one each in the port window, starboard crew door and rear ramp. Chaff and flare dispensers were mounted at various points on the airframe and AN/ALQ-157 IR jammers were placed strategically on top of each gull wing to defeat incoming heat-seeking missiles. In addition, a comprehensive Electronic Warfare (EW) suite was fitted to counter other threats. Even with the vast array of sophisticated on-board systems and sensors, close and continuous crew coordination was absolutely essential in PAVE LOW operations. In the early days of the PAVE LOW I test program, twenty-five experienced HH-53 pilots were interviewed as part of a 10-month study to identify operational CSAR problems relating to cockpit controls, displays and crew station areas.

Results of this study were assessed to determine their impact on operational mission effectiveness. Since that time, crew coordination and training was perfected to a synergistic level in which crews placed total trust in one another in order to survive and accomplish the mission. While pilots concentrated on flying and navigating to and from the objective, they relied heavily on the lead flight engineer – seated between and slightly behind them – to monitor aircraft and system performance throughout the mission. When approaching the objective and once on-scene, a second flight engineer would swap between operating the 600 lb capacity rescue hoist and providing defensive fire suppression from his position in the starboard crew door as needed. The port side of the helicopter was defended by a dedicated aerial gunner through a cabin window behind the cockpit. The tail gunner provided suppressive fire for the rear sector of the helicopter, along with a significant portion on either side, from the open rear ramp.

Figure 19. Nighttime rescue exercises using a hoist

The establishment of integrated crews, a battle-proven concept since the days of World War II, was practiced among the PAVE LOW community and was proven to significantly enhance their combat effectiveness and survivability. The extremely low altitudes which comprised the PAVE LOW's primary operating environment made situational awareness by all crewmembers a critical element in mission accomplishment, particularly since approximately 95% of all PAVE LOW missions were flown at night. A true team effort became paramount when arriving at the rescue site and entering into a hover or landing to retrieve personnel in total black-out conditions. While on-scene, the use of night vision goggles by the crew was an absolute necessity to ensure visual awareness of ground obstacles such as trees, rocks, electrical power lines or other hazards. During "brownout" landings (where sand and dirt are recirculated by the main rotor rendering visibility severely degraded) the verbal crew coordination among the co-pilot, flight engineer and crew was of paramount importance to the pilot who carefully landed the aircraft. The role of the MH-53 in the brownout problem is discussed in section 3.7.4.

3.6 "PAVE LOW Leads"

While supporting various operations around the world throughout the 1980s, such as Operation Just Cause in Panama in 1989, PAVE LOW crews became very adept at their job and were soon recognized throughout the military as some of the best in the business. Their reputation as such made them and their aircraft some of the most sought-after assets in the U.S. military inventory. This accolade came to the fore in 1991 when the PAVE LOW was selected to lead the initial strike package into Iraq to initiate Operation Desert Storm. In order for coalition air forces to successfully penetrate Iraqi air defenses and destroy key targets with the best chances of success, it was necessary to open a sizeable gap in the Iraqi air defense radar network on the Iraqi/Saudi Arabian border. Although the McDonnell Douglas (now Boeing) AH-64A Apache attack helicopter could bring plenty of firepower to bear on the targets, it was not adequately equipped (at the time) to accurately navigate the vast, featureless desert terrain of Southwest Asia for long distances. Therefore, it was decided that a task force of Apaches would be led in tight formation by a pair of MH-53Js using their highly-accurate Global Positioning System (GPS) and INS equipment. The unparalleled accuracy of the on-board systems allowed crews to arrive on-scene within plus or minus 30 seconds of the scheduled time. Acting as pathfinders, the PAVE LOW crews would drop chemical light sticks at pre-determined waypoints along the route to the target, allowing the Apache crews to update their on-board Doppler navigation systems accordingly. In the early morning hours of January 17, the mission took place exactly as planned with the Apaches reaching their objective and scoring direct hits on the radar and communications sites, opening a 20-mile corridor for coalition strike aircraft. The flawless execution of this critical mission played a pivotal role in the success of the war, inspiring PAVE LOW crews to adopt the self-assured motto, "PAVE LOW Leads."

Figure 20. MH-53J during Operation Desert Storm

Figure 21. Combat rescue of downed Navy pilot in Iraq—January 21, 1991

After leading the very first mission of the 1991 Gulf War, the PAVE LOW performed countless other missions, many of which remain shrouded in secrecy even today. Along with the clandestine insertion and extraction of Special Operations Forces throughout the theater of operations, the PAVE LOW also took part in some highly publicized operations, one of which was the rescue of a downed U.S. Navy fighter pilot: the recovery of Lieutenant Devon Jones was noteworthy not only for having been performed under enemy fire in broad daylight, but also for being the first successful Air Force CSAR mission since the Vietnam War. Soon after the Gulf War of 1991, PAVE LOW crews again found themselves in the forefront of regional conflict in places such as Liberia, Haiti and various other locations. When war erupted in the Balkans in

1995, PAVE LOWs were some of the first Air Force assets placed on alert as Operation Deliberate Force commenced. A few years later, during Operation Allied Force, they were involved in the high-profile rescue on March 28, 1999 of the pilot of a downed Lockheed F-117A Nighthawk who evaded capture in Serbian-held territory for more than six tense hours. Two months later, a PAVE LOW rescued the pilot of a downed Lockheed Martin F-16C Fighting Falcon, evading heavy enemy fire for two hours in the process. Aside from performing the traditional CSAR mission, PAVE LOWs carried out numerous Special operations missions in support of troops operating deep behind enemy lines during operations in the Balkans.

3.7 PAVE LOW IV: The Last Generation

After a number of upgrades and improvements over the years, the PAVE LOW appeared in its final variant as the MH-53M PAVE LOW IV. Initiated in 1997, the PAVE LOW IV program aimed to provide the aircraft with enhanced threat detection and defensive capabilities while providing crews with improved situational awareness of the battlefield. Modification of the aircraft, twenty-five in total, took place between 1999 and 2001.The primary internal difference in the Model was the addition of the Interactive Defensive Avionics System / Multi-mission Advanced Tactical Terminal (IDAS/MATT). This advanced system provided crews with near real-time intelligence and threat information from various off-board sensors, allowing them to update their flight profile en route and more effectively avoid known air defenses.

A color, multifunctional, night-vision compatible digital map screen is the most visible hardware in the IDAS/MATT. Located on the helicopter's instrument panel, the display gave an MH-53 crew a clearer picture of the battlefield. Crews were provided with access to near real-time events, including the aircraft's flight route, man-made hazards such as power lines, and even enemy electronic threats that were "over-the-horizon." The system worked by coded satellite transmissions to the helicopter's computer that were then decoded. The data from the screen provided a perspective of potential threats and their lethal threat radius. Besides the map display, a navigational display provided digital course and bearing information with the push of a button. The heart of the system - advanced software - included an integrated electronic warfare system, infrared (IR) countermeasure controls (including missile warning), radar warning and jammer inputs, as well as chaff and flare countermeasures, all of which were monitored on one display. Crews received instant cautions and advisories on threats with immediate recommendations, including when to dispense countermeasures.

Figure 22. MH-53M Pave Low IV deploys flares

With IDAS/MATT, if the computer sensed a threat, it anticipated the threat with a direct action the crew could take. It sensed the problem and offered the crew a way to solve it instantaneously. The entire system was designed with the crew member as a priority in consolidating a variety of functions. Special attention was made to display visible instrument

panel functions with easy console access while increasing the efficient flow of information. In a battlefield situation, concise and near real-time information is perhaps an aircrew's most valuable asset. With IDAS/MATT, the probability of being detected by the enemy was greatly reduced. The system was also readily transferred to other Special operations platforms and is included in the CV-22B Osprey.

The IDAS/MATT upgrade program incorporated the PL IV aircraft system onto the PL III simulation network. This upgrade made possible the software maintenance of the operational flight programs of the MH-53M weapon system. With IDAS/MATT, the MH-53M was the world's most software-intensive and technologically-sophisticated helicopter. Hardware changes included updating the user interface function to reflect PL IV cockpit changes and the addition of an Embedded Computer Systems Line Replaceable Unit (LRU) rack to host PL IV-unique LRUs. Software changes included the modification of 10 existing LRU simulations. In addition, the flight, visual scene driver, and terrain/target simulations were modified. Software block cycle-change/cycle-time dramatically dropped with the Extendable Integration Support Environment upgrade.

In the early spring of 2000, heavy, continuous rainfall in the southeast part of Africa caused severe devastation and loss of life. Particularly hard hit was the country of Mozambique. The WR-ALC/LU Directorate played a substantial supporting role in the relief efforts for that Southeast African nation. On March 2, 2000, the DoD authorized U.S. military forces in Europe to provide logistical and humanitarian relief support to the area through Operation Silent Promise. The DoD also authorized the 352 SOG from RAF Mildenhall UK to deploy up to six MH-53M helicopters for the relief effort. Only five were actually needed.

In FY02, WR-ALC employees upgraded two of the remaining MH-53Js to MH-53M configuration with kits left over from the original IDAS/MATT program. At the end of FY02, the fleet size stood at 11 MH-53Js and 25 MH-53Ms, due to two losses during Operation Enduring Freedom (OEF). Plans called for the remaining MH-53Js to be converted to MH-53M configuration beginning with a FY03 new start in compliance with the PMD direction. Officials also anticipated the fielding of a new MH-53M configuration calculated to correct system obsolescence and vanishing vendor issues that exist with the currently fielded IDAS/MATT equipment. Experts decided not to add any new capabilities. They expected these modifications to correct existing production deficiencies. Once the new configuration was designed, tested, and fielded on the 11 MH-53Js, the original 25 MH-53Ms would be upgraded in the out years to the new common configuration. Upon program completion, HQ AFSOC would have a fleet of 36 operational aircraft in the same IDAS/MATT configuration.

3.7.1 MH-53M Mission Capable Rate

During recent years, all MH-53 stakeholders realized that the MH-53M Mission Capable (MC) rate and Aircraft Availability rate were critical performance metrics for determining whether HQ AFSOC and U.S. Special Operations Command (USSOCOM) would have the fully-operational aircraft available to meet National Command Authority (NCA) taskings. As such, the SOF SPO, HQ AFSOC, Defense Logistics Agency (DLA), depot repair organizations, and suppliers had worked very hard with remarkable results that assured sustainment of outstanding MC rates. From 1997 to 2000, the average MC rate increased from 56 percent to 80 percent. However, this MH-53M MC rate and Aircraft Availability could not be maintained at that level

without the funding of operational and sustainment modifications. Between 1999 and 2002, the MH-53J/M fleet MC rate averaged 80 percent, with the highest monthly MC rate reaching 86.9 percent. Driven by the universal belief among the MH-53 work force that no detail was too small, the MH-53M MC rate success had been attained through vigorous supply chain management which employed thorough use of military supply sources, use of commercial vendors, search of international markets, review of reclamation venues, and ingenious repair efforts.

Just as the development of the entire prototype helicopter helped reduce cost and risk in the MH-53 program, competitive prototyping of subsystems and components also helped reduce risk and cost in the program. Nearly every subsystem added to the PL was prototyped and tested at Hurlburt Field FL. These subsystems included radios, guns, navigation aids, etc. AFSOC developed a formal test flight for the PL with AFOTEC (Air Force Operational Test and Evaluation Center) as well as a DT&E (Developmental Test and Evaluation) group. They also received outstanding support from both government and contractor repair facilities as well as the hard working men and women on the flight lines and back shops at all Air Force PAVE LOW operating locations.

In FY02, increased operations tempo (OPSTEMPO) invoked by OEF resulted in an inordinate number of repairs. In some cases, this meant repairing gearboxes in just eight months, a task which would normally be done in three years during peacetime. During FY02, pieces and parts (gears, splines, bearings, gaskets, shafts, seals) for gearboxes were in short supply. These gearboxes were last manufactured in quantity in the mid-1980s. Many of the piece part vendors had gone out of business, while the MH-53M industrial base had shut down. Moreover, the remaining Navy CH-53E vendors did not manufacture equipment suitable for the essentially 1960s-vintage MH-53M. The only way to get piece part vendors back into production again was to place a substantial order. The SOF SPO recommended the order be for 41 complete sets of the gearbox assemblies placed with Sikorsky Aircraft Inc. (United Technologies Corporation) Headquarters in Stratford, Connecticut, the Original Equipment Manufacturer (OEM). The SOF SPO concluded that once the piece part vendors resumed business operations, there would be sources for piece part procurement to support future repair requirements.

3.7.2 AN/AAQ-24(V) Directed Infrared Countermeasures (DIRCM)

Figure 23. AN/AAQ-24(V) DIRCM

The AN/AAQ-24(V) Directed Infrared Countermeasures (DIRCM) program was one of U.S. Special Operations Command's (USSOCOM's) highest priority acquisition programs. This urgently-needed aircraft self-protection suite provided fast and accurate threat detection, processing, tracking, and countermeasures to defeat current and future generation infrared missile threats. DIRCM was designed for installation on a wide range of rotary-wing and fixed-wing aircraft. For USSOCOM, the system was installed on all of Air Force Special Operations Command's (AFSOC's) AC–130 gunships and MC–130 Combat Talon aircraft. A laser-based jamming capability was developed and shortly thereafter installed on the MH-53M. Additionally,

installation of the DIRCM system integrated a fully automatic mode to the chaff and flare dispenser system to more effectively counter radar-directed and IR-based threats.

3.7.3 PLs Undergo Service Life Extension Program (SLEP) Enhancements

As a low-density/high-demand asset, the PAVE LOW was one of the most highly-tasked platforms in the Air Force. In total, only 41 airframes received the PAVE LOW modification. Its heavy use in all theaters of operation around the globe was taxing on the airframe. To maximize its usefulness and longevity, the entire PAVE LOW inventory underwent a SLEP beginning in the mid-1990s, receiving numerous upgrades and new components. The purpose of the MH-53 SLEP was to expand the operational gross weight capability and enhance the structural integrity of the MH-53J PL III. The SLEP saw an increase in the gross weight (GW) from 42,000 to 50,000 lbs in order to provide a capable air vehicle beyond the year 2000.[7] CSAR operational requirements were also addressed to meet the future DoD long-range helicopter needs. This SLEP enhanced the ability of the MH-53J to deploy to extreme ranges at maximum GW which allows for a limited number of weapon systems to be strategically based. Extensive airframe modifications were also accomplished at the Naval Aviation Depot in Pensacola.

Key air vehicle elements of the MH-53J PL III SLEP, which included the addition of Shipboard Operations (SBO) features, were:

- Improved main rotor blades
- Elastomeric main rotor head
- T-64-GE-100 engines
- Increased strength accessory gearbox support structure
- Automatic tail pylon fold system for SBO
- RH-53D main landing gear
- Stronger alloy tail pylon skins
- Structural enhancements in the aft fuselage upper/side skins
- Improved/replaced aircraft electrical wiring system
- New aircraft hydraulic tubing
- Exhaust cooler for auxiliary power plant
- Collective damper

The SLEP not only allowed the PAVE LOW to continue flying despite its considerable age, but it also provided enhanced mission capabilities. Having seen its first major conflict during Operation Allied Force in 1999, the PL IV again entered large-scale combat when the Global War on Terror (GWOT) began at the start of OEF in Afghanistan in September 2001. Eighteen months later, when the invasion of Iraq occurred in March 2003, the PAVE LOW was again at the forefront of combat during OIF. Both of these conflicts were significant for their heavy emphasis on Special operations, a task for which the PAVE LOW and its crews proved immensely effective. As in previous conflicts, the PAVE LOW was often – not surprisingly – one of the first assets present within a given theater of operations.

Effective systems engineering planning of the SLEP for the PAVE LOW program (1) extended the usability of the weapon system into the 21st century which enabled it to play a crucial role in the GWOT starting in 2001, and (2) allowed the PAVE LOW to remain viable until its replacement, the CV-22B, could be fielded.

3.7.4 Beating Brownout on the PL IV

Between 1985 and 2005, the Air Force experienced Seven Class A (and B) mishaps in their H-53 aircraft due to rotary-wing brownout (RWB).[8] Until recently, a Class A mishap was defined as a mishap in which there was $1M or more in damage to the aircraft or death/ permanent total disability of the aircrew. A Class B mishap was a mishap with greater than $200K but less than $1M in damages or a permanent partial disability to the aircrew.[v]

All of the U.S. armed services consider landings in dense, recirculating dust, sand, or snow a hazard to helicopters and tilt-rotors.[9] The Office of the Under Secretary for Defense Installations and Environment notes brownout mishaps cost more than $100 million per year and accounted for a third of all helicopter accidents in OEF and OIF.

Figure 24. Onset of Rotary-Wing Brownout conditions

In 2006, the Air Force Research Laboratory (AFRL) initiated a study program directed at reducing or eliminating the RWB problem. RWB is the condition that results when a helicopter lands in an arid environment and the rotors recirculate sand and dust such that visibility out of the cockpit is severely reduced. The MH-53M program figured prominently in the RWB study. Four AFSOC aircrew members were attending the Air Force Institute of Technology (AFIT) in 2005-6 and were engaged in the study by then-Major Lee Anderson (co-author of this Case Study). The foursome was able to develop the evaluation criteria for the RWB technology developed during the study. Anderson and the others were able to develop specific criteria for landing in degraded visual environments including brownout. Blinding sand and dust clouds churned up by helicopter rotors still cost the U.S. armed services lives and aircraft in ongoing conflicts. Since 2002, the Army alone has lost or damaged 27 helicopters in brownout mishaps. Recently, a Special Operations MH-47 Chinook hit a hidden obstacle on takeoff and crashed, resulting in 10 fatalities.

The Air Force, Navy, and Marine Corps likewise have suffered losses operating at unprepared sites in dense, recirculating dust.[10] Better crew training and improved cockpit symbology and flight controls have provided some help in addressing the common threat of brownout. Singly, and in partnership, the services and the Defense Advanced Research Projects

[v]Effective 1 October 2009 Class A: Total cost of damages in an amount of $2 million or more; or destruction of a DoD aircraft; or injury/occupational illness resulting in fatality; or permanent total disability. Class B: Total cost of damages in an amount of $500,000 or more, but less than $2 million; or injury/occupational illness resulting in permanent partial disability; or hospitalization of three or more personnel as a result of a single accident.

Agency (DARPA) meanwhile are pursuing advanced see-through, see-and-remember, and combination technologies for safe landings in desert dust.

Cuing symbology also works with integrated flight controls to enhance stability in brownout. The AFSOC upgraded MH-53M PL IV and HH-60G Pave Hawk helicopters with an Altitude Hold Hover Stabilization system and improved cockpit symbology. Marine MV-22B and Air Force CV-22B Osprey tilt-rotor aircraft have flight path vector displays that let crews make brownout landings manually with cues on the hover indicator or automatically using the fly-by-wire hover-hold function.

Hover symbology and enhanced flight controls nevertheless do nothing to avoid landing zone (LZ) obstacles hidden by dust clouds. In 2006, AFRL tested the Photographic Landing Augmentation System for Helicopters (PhLASH) on an MH-53M PL IV. Applied Minds Inc., of Glendale, California, built a gimbaled, 16 mega-pixel camera with an IR strobe and laser rangefinder to image the LZ before entering the cloud. The pilot saw a clear picture of the LZ as it existed 20 to 30 seconds before landing, geo-registered on the real world with a GPS receiver and inertial measurement unit. The see-and-remember PhLASH had the resolution to spot small obstacles but could not show hazards entering the LZ after brownout occurred.[11] The goal of the AFRL RWB study was to develop a “see-through” capability.

AFRL brownout researchers concluded that laser radar (LADAR) could provide far better spatial resolution than Millimeter Wave (MMW) radar to spot LZ obstacles. The 3D-LZ (Three-Dimensional Landing Zone) collaboration by AFRL and AFDD (AeroFlight Dynamics Directorate at NASA Ames) integrated LADAR with an intuitive BrownOut Symbology System (BOSS). The LADAR updated a dynamic navigation database that showed pilots color-enhanced obstacles. BOSS cues developed by AFDD consolidated and improved elements of BSAU (Brownout Situational Awareness Upgrade) symbology to give pilots essential flight parameters with reduced workload. The 3D-LZ landings touched down at 0 to 1 knots, with descent rates less than 50 feet per minute. Test pilot and AFDD flight projects office chief Lt Colonel Steve Braddom noted, “They weren’t the typical aggressive landings you see in brownout.”

To provide a true multi-purpose helicopter sensor, AFRL researchers envision 3D-LZ laser technology integrated with navigation FLIR. Sandblaster[vi] program managers, meanwhile, consider Sandblaster “sensor-agnostic” and compatible with a mix of imaging technologies. Additionally, DARPA is working with USSOCOM and Army aviation leaders to transition the technology to a production brownout aid. The technology came along too late for the PL IV, however, the PAVE LOW mission helped initiate the technology needed for the RWB system which will be a valuable asset on other rotary-wing aircraft.

[vi]Sandblaster is the program name given to a DARPA program whose goal was to reduce, if not eliminate, degraded visual effects of brownout in helicopters.

3.8 From the Battlefield to the "Boneyard"

Figure 25. Final Pave Low mission—September 26, 2008

Given adequate funding and no end in sight for the PAVE LOW mission, the Air Force had originally planned to retain the aircraft in service possibly as late as 2014. However, the inevitable rise in maintenance costs and the increasing number of maintenance man-hours required per flight hour to keep the PAVE LOW flying took its toll. The MH-53M, like all previous variants, was equipped with the vintage radar and FLIR with which the PAVE LOW had originally entered service, and lacked IR engine exhaust suppressors. This resulted in not only having the highest maintenance requirements in the entire AFSOC aircraft inventory, but it also posed a significant vulnerability to shoulder-fired surface-to-air missiles. Additionally, ever-increasing reductions in funding meant that the PL IV program turned out to be the last major upgrade of the type. Even as the first MH-53J was retired on January 4, 2007, the PAVE LOW remained a highly effective, fully mission-capable platform with no operational flight restrictions, and the airframe had no structural fatigue problems. Even as late as June 2008, PAVE LOW crews were engaged in low-level flight training in the mountains and valleys surrounding Roanoke, Virginia. The final operational combat mission for the PAVE LOW took place on September 26, 2008, during a logistical resupply and passenger movement mission supporting Special Operations Forces in central and southern Iraq as part of OIF, bringing an end to a distinguished career of nearly 30 years. Fittingly, the mission took place under the cover of total darkness.

Figure 26. Retired Pave Low in outdoor storage at Davis-Monthan AFB, AZ

Like many before them, most of the last PAVE LOWs to see action were transported directly from the theater of operations to the 309th Aerospace Maintenance and Regeneration Group (309 AMARG), affectionately known as the "Boneyard," adjacent to Davis-Monthan AFB, Arizona. Those that were not taken to the Boneyard found their way to museums around the country, ensuring their place in history as a symbol of freedom and the heroes they supported. As the drawdown of the PAVE LOW occurred, some units chose to commemorate the service of this remarkable aircraft with formal ceremonies honoring the type. One of those, the 20th Special Operations Squadron (20 SOS), held the distinctive honor of being the last unit to operate the PAVE LOW. A formal retirement ceremony, attended by scores of military and civilian guests, was held on October 17, 2008, at Hurlburt Field, Florida. Pilots, aircrew members, maintainers and various others who were involved with the PAVE LOW at

one time or another all gathered to bid a fond farewell to the machine they knew and admired. In the Hurlburt Field Air Park, an MH-53M now sits immortalized on permanent display.

Figure 27. Formal PAVE LOW retirement ceremony—October 17, 2008

Figure 28. Bell Boeing CV-22B Osprey tilt-rotor

As the decision was made to retire the PAVE LOW and the type was gradually withdrawn from service, the Air Force endeavored to introduce the Bell Boeing CV-22B Osprey tilt-rotor into full operational service as a partial replacement for the PAVE LOW. While the Osprey's superior speed and range allow it to perform long-range infiltration/exfiltration and resupply, differences in flight profile, performance, and capability as compared to the PAVE LOW have not allowed it to fill completely the void left behind by the MH-53J/M. Instead, the remainder of the PAVE LOW mission is now carried out by Army Special Operations helicopters such as the Boeing MH-47E/G Chinook.

Figure 29. Boeing MH-47E Chinook (Special Operations Variant)

4 Conclusion

The Sikorsky MH-53 PAVE LOW III helicopters were originally HH-53B/C Super Jolly Green Giants, or “Super Jollies,” used by the U.S. Air Force in the Vietnam War. The requirement to perform combat rescue missions during periods of darkness before the introduction of night vision technology drove several attempts to modify the H-53. After several unsuccessful attempts, the PAVE LOW III program successfully developed an effective design which included advanced inertial and Doppler navigation systems, a Forward-Looking Infrared (FLIR) sensor, automated hover stabilization and Terrain-Following/Terrain-Avoidance (TF/TA) radar. Eight operational HH-53C aircraft were modified and became known as the HH-53H PAVE LOW III capable of flying low level missions at night and in adverse weather. The success of this program eventually led to the evolution of all 41 HH-53 aircraft in the USAF to the MH-53J PAVE LOW III enhanced configuration. These aircraft were designated for Special operations and were subsequently given Global Positioning System (GPS) navigation systems, improved engines and rotor blades as well as structural reinforcement to extend the life of the airframes and increase the maximum operating weights during the 1980s. The MH-53J became famous during Desert Storm when used to lead AH-64 aircraft to conduct initial strikes against Iraqi surface to air missile systems and enable to start of the air war. During the late 1990s the aircraft received another major upgrade to the avionics including improved defensive systems integration, a color digital map display and a satellite intelligence receiver to improve situational awareness and survivability. These modified aircraft were now designated MH-53M and were informally known as PAVE LOW IV and first saw combat employment in Kosovo. Throughout its lifespan, Air Force Special Operations Command (AFSOC) employed the PAVE LOW to conduct long-range, low-level insertion, extraction and resupply of Special Operations Forces (SOF) from all branches of the US military.

An effective systems engineering plan for system modifications and upgrades via the SLEP extended the life of the aircraft while enhancing its usability. Originally designed for a 10-year service life, some of the modified H-53 aircraft had tail numbers ranging from 66 (built in 1966) to the early 70s. The PAVE LOW SLEP helped keep the weapon system viable for an additional 15-20 years with final retirement in 2008.

Figure 30.Overwater flight of an MH-53M at dusk

Indisputably, the PAVE LOW established a solid and well-deserved reputation for performance and reliability among its crews and maintainers. Its high mission-ready rate was a testament not only to the hardworking maintenance crews, but also to the sheer ruggedness of the H-53 airframe. Having performed countless clandestine military operations across the globe, ranging from the small-scale conflicts of the 1980s to the recent liberation of Iraq and the ongoing campaign in Afghanistan, the PAVE LOW will be remembered as a true warrior. The “cloak-and-dagger” nature of Special operations dictates that many of the missions undertaken by the PAVE LOW and her valiant crews will remain shrouded in secrecy for years to come. Eventually, when these missions are one day made public, the true

valor and bravery inherent in the PAVE LOW community will be revealed. In addition to its secretive wartime role, the PAVE LOW provided valuable assistance in peacetime disaster relief and humanitarian support missions in numerous places around the world. In the aftermath of Hurricane Katrina, PAVE LOWs provided airlift for equipment, supplies and personnel in the massive relief effort. A case in point, less than one month prior to retirement, a PAVE LOW was placed on standby in September 2008 to assist the U.S. Coast Guard on a mission to rescue the crew of a Cyprus flagged freighter adrift in the Gulf of Mexico in the midst of Hurricane Ike. Despite being a conversion of an existing platform rather than one built for the mission from the ground up, the PAVE LOW had no peer in nighttime low-level penetration capability. The PAVE LOW was viewed by many as the premier CSAR and Special operations helicopter, a sentiment enthusiastically shared by virtually all who flew it. Indeed, many crewmembers, both newcomers and seasoned veterans, have proclaimed that the PAVE LOW was – and will remain – the absolute peak of their career. Even in retirement, the PAVE LOW leaves behind a legacy as the largest, most powerful and most technologically advanced helicopter ever to fly in the Air Force inventory. In the words of Lieutenant Colonel Gene Becker, Commander of the 20th Expeditionary Special Operations Squadron (20 ESOS) in Iraq which flew the final PAVE LOW combat mission, "She goes out, as she came in – the very best."

Figure 31. MH-53M PAVE LOW IV, National Museum of the U.S. Air Force, Dayton, Ohio

Appendix A A Framework of Key Systems Engineering Concepts and Responsibilities

Concept Domain	Responsibility Domain		
	1. Contractor Responsibility	**2. Shared Responsibility**	**3. Government Responsibility**
A. Requirements Definition and Management			
B. Systems Architecting and Conceptual Design			
C. System and Subsystem Detailed Design and Implementation			
D. Systems and Interface Integration			
E. Validation and Verification			
F. Deployment and Post Deployment			
G. Life Cycle Support			
H. Risk Assessment and Management			
I. System and Program Management			

This Friedman-Sage matrix is included as an exercise for the student. Following the explanation in Section 1.5 of this Case Study develop 4-6 systems engineering learning principles from the case study and then insert them into the matrix based on whether they were a contractor responsibility, a government responsibility, or a shared responsibility between the government and the contractor.

Appendix B: Author Biographies

William Albery, Ph.D. is the Chief Scientist of Innovative Technologies Corporation (ITC) in Dayton, Ohio. He is a retired 36-year civilian (U.S. Air Force) who technically managed the Wright Patterson AFB human centrifuge facility. From 2005-2008, he was the Crew Interface Systems Engineer on the Air Force Research Laboratory's Rotary-Wing Brownout (RWB) study. In 2007, he organized and now leads a North Atlantic Treaty Organization (NATO) RTO Task Group on RWB that has 9 countries and 20 scientists/engineers and pilots participating. He received his Bachelor's of Science degree in Systems Engineering from Wright State University (WSU) in 1971, his Master's Degree in Biomedical Engineering from The Ohio State University (OSU) in 1976, and his Doctorate (PhD) in Biomedical Sciences from WSU in 1987. He is an Associate Professor in the WSU School of Medicine, a Fellow of the Aerospace Medical Association, a Fellow of the Aerospace Human Factors Association, and past President of the SAFE Association. Dr. Albery was a co-author for the AFIT MQ-1/9 Case Study and the author of a Case Study for the C-17. He is co-PI on the MH-53J/M Case Study and the PI on the E-10 Case Study, also for the AFIT Center for Systems Engineering.

Raymond L. Robb grew up in Savannah, Georgia, where he developed a passion for aviation at an early age. Living in the shadow of Hunter Army Airfield, he was accustomed to frequent overflights of military aircraft of all types, a contributing factor to his decision to join the United States Air Force. While on active duty, he served for a number of years at Royal Air Force Mildenhall in the United Kingdom, followed by an assignment at Regional Headquarters Allied Forces North Europe in Brunssum, the Netherlands. Upon completion of nearly ten years of service, he left the Air Force with an Honorable Discharge for a position at the Defense Advanced Research Projects Agency (DARPA) in Arlington, Virginia. From there, he later relocated to Wright-Patterson Air Force Base in Dayton, Ohio, where he supported numerous programs as a Contractor within the Aeronautical Systems Center (ASC) prior to becoming an Air Force Civilian. In this capacity, he currently works in the Air Force Research Laboratory (AFRL) under Air Force Materiel Command (AFMC) at Wright-Patterson AFB. Outside of work, he continues to be an avid aviation enthusiast, photographer, and historian. His continued interest in the preservation of aviation history serves him well in his position as President of the Dayton Chapter of the American Helicopter Society (AHS). In addition, he is a freelance writer and Contributing Editor for *Vertiflite* magazine. His articles and photos have appeared in a number of publications read worldwide. He currently works in the Materials & Manufacturing Directorate of AFRL. He is an avid aviation enthusiast, photographer, and historian. His article, *Darkness Falls: A Farewell to the PAVE LOW* (*Vertiflite, Winter 2008, Vol. 54, No. 4*), was the basis for the narrative of this Case Study.

Lt Col Lee Anderson is a 1992 Air Force Academy graduate (Aeronautical Engineering) as well as a 2006 AFIT Systems Engineering graduate. Lieutenant Colonel Leighton "Lee" Anderson is Commander of the 1st Special Operations Support Squadron, Hurlburt Field, Florida. He directs a squadron with over 400 officer and enlisted personnel who are charged with a myriad of flying operations support functions. Mission include air traffic control, airfield management, combat medicine, intelligence, weather, current operations, aircrew

training, range support, aircrew life support, and joint liaisons. Lieutenant Colonel Anderson earned his commission upon graduation from the United States Air Force Academy in 1992. He completed Undergraduate Pilot Training in 1993 and has served as an instructor and evaluator pilot. He is a senior pilot with over 3,000 flying hours in the UH-1N, MH-53J/M, C-12 and V-22 with combat experience in Operations ALLIED FORCE, SOUTHERN WATCH, ENDURING FREEDOM, and IRAQI FREEDOM. Selected as initial cadre for the CV-22, he has extensive experience developing, testing, and fielding advanced solutions to improve combat effectiveness for Special operations vertical lift aircraft. Anderson was a member of the AFRL Rotary-Wing Brownout (RWB) Integrated Study Team from 2006-2008. He and his AFIT colleagues developed the Systems Engineering Plan for the AFRL Integrated RWB study and helped define the criteria for performing safe landings in Degraded Visual Environments.

ROC 19–70

23 JULY 70

A REQUIREMENT EXISTS FOR AN INTEGRATED SYSTEM TO ENABLE A RESCUE VEHICLE TO PERFORM SEARCH AND RESCUE UNDER CONDITIONS OF TOTAL DARKNESS AND/OR ADVERSE WEATHER IN ALL GEOGRAPHICAL AREAS INCLUDING MOUNTAINOUS TERRAIN. ADDITIONALLY, THE RESCUE VEHICLE MUST HAVE A LOW LEVEL CAPABILITY TO PENETRATE HOSTILE TERRITORY AGAINST RADAR DIRECTED WEAPONS IN THE ABOVE STATED ENVIRONMENTAL CONDITIONS

EXHIBIT 3

25 CHAPTER IV

SEARCH AND RESCUE REQUIREMENTS
MAC ROC 19-70

26 CHAPTER IV

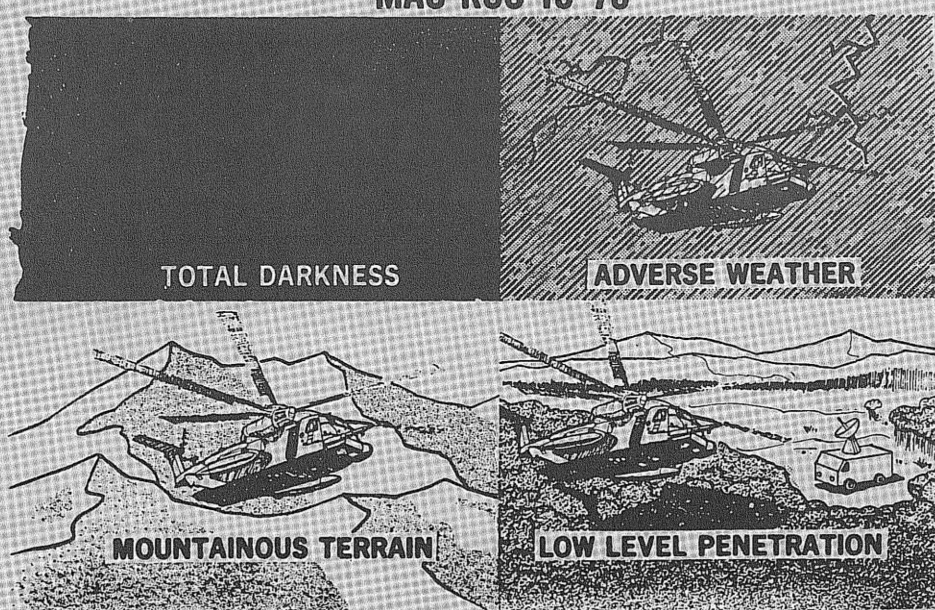

EXHIBIT 4

Appendix D: 1974 PMD

28
CHAPTER V

HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON D.C.

PMD NO. R-P3009(2) 64212F/5551 DATE: 30 January 1974

HQ USAF PROGRAM OFFICER MAJOR RUFFING OFFICE SYMBOL AF/RDPND

HQ USAF PROGRAM MONITOR LT COL ROBBINS OFFICE SYMBOL AF/RDQRA

PROGRAM MANAGEMENT DIRECTIVE
FOR
HH-53 HELICOPTER NIGHT ADVERSE WEATHER
RESCUE SYSTEM PROTOTYPE (PAVE LOW III)

1. SPECIFIC PURPOSE: This directive provides FY 74 approval, supersedes R-P 3009(1)/64212F, establishes priorities, and provides program guidance for Project 5551, P.E.64212F, Aircraft Equipment Development. Air Force Systems Command is designated the implementing command for the program defined by this PMD.

2. PROGRAM SUMMARY:

a. SCOPE: The purpose of the PAVE LOW III program is to develop an integrated system as specifically defined in Ref 6 with atch, to enable a rescue helicopter to perform low-level, night/adverse weather search and rescue operations in worldwide terrain environments.

b. References:

(1) MAC ROC 19-70, July 1970, (S)

(2) CSAF/RDP 152020Z March 1972 to AFSC, subj: PAVE LOW Continuation Program

(3) AFSC/SDNS 222214Z March 1972 to CSAF/RDPN, subj: PAVE LOW Continuation Program

(4) CSAF/RDQ 242000Z April 1973 to AFSC, subj: PAVE LOW II Production Prototype

(5) MAC/DO 031705Z May 1973 to AFSC, subj: MAC Concurrence in Alternate Approach

(6) AFSC/SDAE letter, 8 June 1973 to Hq USAF/RDQ, subj, PAVE LOW Night/Adverse Weather Rescue System Prototype, (S)

(7) CSAF/RDP 121743Z July 1973 to AFSC/SD, subj: Approval of AFSC Proposed Program.

c. Priority Category: The PAVE LOW Program is assigned a USAF Precedence Rating of 2-6 and Importance Category of 1 (IC-1).

EXHIBIT 5a

d. Program Objectives: The approved program will install and integrate the following additional equipment into an HH-53 Helicopter, S/N 66-14433:

(1) Navigation System
- Central Computer
- Inertial Platform
- Doppler
- Map Display
- Terrain Following/Avoidance Radar
- Air Data System
- Associated Controls, Displays and Interface

(2) Sensor
- Forward Looking Infrared Sensor
- Stabilized Platform
- Associated Controls, Displays and Interface

3. (U) SCHEDULE: Flight test results, cost factors and modification design data must be available by the end of FY 75 for final production/modification decision, as indicated in Reference 6 above. AFSC will provide appropriate milestone data subsequent to the release of FY 75 funds.

4. (U) PROGRAM MANAGEMENT:

a. Air Force Systems Command is the designated implementing command for this program and is responsible for design, development and test of the prototype rescue system.

b. Military Airlift Command will coordinate with Air Force Systems Command during the design, development and test phases in order to assure that the resulting prototype system will be responsive to the using command's mission.

c. Air Force Logistics Command will coordinate with and support Air Force Systems Command in providing inventory Government Furnished Equipment during all phases of this program.

5. (U) FUNDING

a. The total P-3600 program funding requirement is $3.0M as per Ref 6.

(1) $400K is immediately available to initiate the tasks outlined in Reference 6.

(2) FY 75 funds in the amount of $2.2M are programmed to continue the PAVE LOW III effort. The remaining $400K will be addressed during the FY 75 apportionment.

6. (U) TEST AND EVALUATION: A combined DT&E/IOT&E of the prototype will be conducted IAW AFR 80-14. MAC will make T&E inputs to the test plan and will participate actively throughout the prototype flight test program. MAC will assist AFSC as required in developing the PMP and in identifying and addressing critical questions and issues associated with operational suitability, reliability, and maintainability. MAC will submit independent IOT&E reports to AF/XOOW NLT 60 days after completion of testing. Test and evaluation specifics will be provided in the next update of this PMD.

7. (U) GENERAL GUIDANCE

a. A quarterly R&D Management Report (AF Form 111) is to be submitted by the project manager at the end of each fiscal quarter. The report will cover the status of the project, actions under way, problem areas and funds status.

b. At the completion of the FY 74 phase and prior to the release of FY 75 funds a briefing will be requested from Air Force Systems Command to provide this Headquarters with the results of FY 74 expenditures and the proposed development and production/modification costs and schedules associated with the release of FY 75 funds.

8. (U) SECURITY:

a. The basic PAVE LOW program is unclassified.

b. The performance specifications of major PAVE LOW components (FLIR, etc) will be classified according to existing security guidance applicable to that component.

c. Flight test details which indicate operational performance of the system and tactics will be classified confidential until downgraded by the using command.

d. HQ AFSC will provide a Security Classification Guide if required.

FOR THE CHIEF OF STAFF

Benton K Partin

BENTON K. PARTIN, Brig Gen, USAF
Deputy Director of Development
and Acquisition, DCS/R&D

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EXHIBIT 5c

Appendix E: AN/APQ-158 TF/TA Radar

TF/TA RADAR SYSTEMS
AN/APQ-158

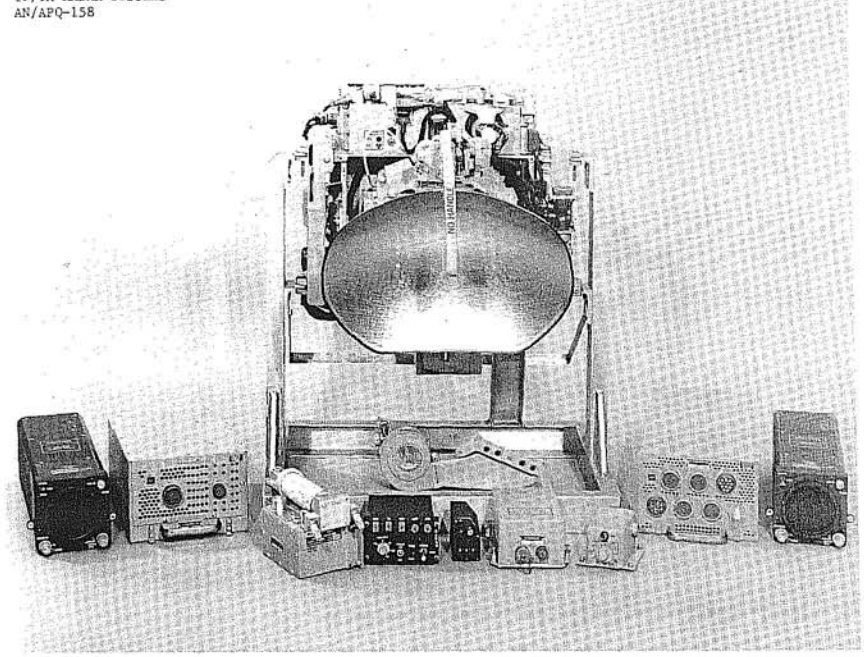

FIGURE 20

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Appendix F: PMD 1977

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CHAPTER XII

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C. 20330

PMD No.: L-Y 7088(1)
Modification No.: 2996
HQ USAF Program Officer:
Maj Linenberger/RDQRA/74138

Date: 29 April 1977

HQ USAF Program Monitor:
Lt Col St. Louis/LGYYS/50844

PROGRAM MANAGEMENT DIRECTIVE
FOR
CLASS V MODIFICATION, HH-53 PAVE LOW III SYSTEM

FOR: AFSC, AFLC, ATC, MAC and AFTEC

1. Specific Purpose. This PMD implements Class V Modification Number 2996 to install the Pave Low III, Night/Adverse Weather Rescue System, in eight HH-53C aircraft. AFSC is the implementing command, AFLC and ATC are supporting commands, and MAC is the operating command. AF/LGYYS will be the Air Staff Office of Primary Responsibility. AF/RDQRA, AF/LGXW, AF/RDPV, and AF/XOORA will be Offices of Corollary Responsibility.

2. Program Summary.

a. References.

(1) MAC ROC 19-70, Night/Adverse Weather Rescue System, 23 July 1970 (Required).

(2) Program Management Directive, R-Q 7053(1), 28 Feb 1977 (Required).

(3) AFSC/ASD Pave Low III Production Program Management Plan, ASD/SDX 74M-01, 4 March 1977.

(4) AFSC/ASD Class V Modification Proposal and Analysis Summary, Pave Low III, 4 March 1977.

b. Priority. Precedence rating 2-6 (FAD II).

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EXHIBIT 22a

c. Required Operational Capability. A modification is required to provide the HH-53C with a night/adverse weather rescue capability. The specific configuration should be similar to the Pave Low III prototype aircraft and include those changes identified during the DT/IOT&E. Aircraft selected for the Pave Low III modification will be equipped with the upgraded T-64-7A engine configuration to accommodate the increased gross weight of the Pave Low system.

d. Scope. Eight HH-53C aircraft will be modified.

3. Program Management Direction. The following actions are mandatory. HQ USAF/RDQ/LGYY will be notified immediately of any inability to comply.

a. AFSC will:

(1) Be responsible for the overall management and integration of the modification program.

(2) Procure Group A kits and provide for the installation of the subsystems.

(3) Procure new and modified Group B equipments.

(4) Obtain Group B equipments currently in Air Force inventory from AFLC.

(5) Establish verification/validation testing procedures to insure all procured items meet original specifications.

(6) Conduct flight testing of the production modified aircraft to insure system is not degraded from the prototype.

(7) Issue a Record Time Compliance Technical Order defining the modification, including the engines, and provide a basis for configuration status accounting.

(8) In conjunction with:

(a) AFLC, MAC and ATC, prepare a detailed logistic support plan to include organization, intermediate, and depot level maintenance.

(b) AFLC, identify and procure the peculiar support equipment required.

(c) AFLC, identify the common support equipment required.

(d) AFLC and MAC, assist in revising equipment authorization documents to insure timely delivery of the required support equipment.

(e) AFLC, assist in provisioning for and procuring spares.

(f) AFLC, MAC and ATC, determine the operational and maintenance manning adjustments necessary and the operational and maintenance training required.

(g) AFLC, procure the necessary technical data, changes and/or additions to existing handbooks, manuals, drawings and specifications. Assure delivery of all required technical data to MAC prior to transfer of first modified aircraft.

(h) AFLC and MAC, determine and contract for contractor support necessary to provide maintenance support until depot and operating units have organic maintenance capability in accordance with the logistic support plan.

(i) MAC and AFLC, develop the modification schedule.

(j) AFLC, identify and, where appropriate, obtain procurement data and lists to insure future reprocurement of similar subsystems and aircraft modification.

(9) Coordinate with AFLC all changes to technical requirements, specifications, program costs, and delivery schedules.

(10) In coordination with AFLC, prepare and publish a Program Management Responsibility Transfer Plan in accordance with AFR 800-4. Program Management Responsibility transfer date is established as FY 2/80.

b. AFLC will:

(1) Actively participate throughout the planning and implementation of the modification program, including source selections. Provide sufficient manpower and support to insure that program schedules are met, that the system is fully supportable when operational, and that the Program Management Responsibility Transfer is orderly.

(2) In conjunction with:

(a) AFSC, MAC and ATC, assist in the preparation of a detailed logistic support plan.

(b) AFSC, procure Group B equipment that is currently in the Air Force inventory.

(c) AFSC, provision for and procure spares for Group A and Group B equipments.

(d) AFSC, procure the common support equipment.

(e) AFSC and MAC, revise equipment authorization documents to insure timely delivery of the required support equipment.

(f) AFSC, MAC and ATC, determine the maintenance manning and training requirement.

(g) AFSC, assist in making the necessary changes and/or additions to existing handbooks, manuals, drawings and specifications, to include the engines in the T-64-7A configuration.

(h) AFSC, assist in identifying required procurement data and list necessary for future reprocurement.

(i) AFSC and MAC, develop the modification schedule.

(3) Assist AFSC in the coordination of all changes to technical requirements and specifications, and program costs and delivery schedules.

(4) In coordination with AFSC, prepare and publish a Program Management Responsibility Transfer Plan in accordance with AFR 800-4.

(5) With the assistance of AFSC and MAC, determine and provide the HH-53 spares and support equipment required during modification installation and acceptance testing.

(6) Assist AFSC in the preparation of the record TCTO.

(7) Identify and designate an appropriate quantity of T-64-7A engines from inventory to support the eight Pave Low aircraft.

(8) Assist MAC in obtaining and installing T-64-7A engines in the aircraft to be modified.

c. MAC will:

(1) Participate and assist in the modification program as requested by AFSC and AFLC. Participation should include:

(a) Providing an HH-53 pilot for liaison with the program office during the program.

(b) Providing a crew chief for maintenance assistance during the aircraft modification and testing.

(c) Providing aircrews as required to fly verification and acceptance test at the modification facility.

(d) Providing maintenance support, including peculiar HH-53 support equipment and technicians, as needed, during the verification and acceptance test.

(2) Provide the aircraft in the appropriate configuration as requested by AFSC. Aircraft should be configured with the T-64-7A engine and have a minimum number of pending inspection requirements.

(3) In conjunction with:

(a) AFSC and AFLC, determine organization and manpower requirements.

(b) AFSC, AFLC and ATC, determine the need for maintenance training and arrange the training schedule with ATC.

(c) AFSC and AFLC, review requirement authorization documents.

(4) Conduct a follow-on OT&E in accordance with AFR 80-14.

d. ATC will:

(1) Validate the training requirements in conjunction with AFSC, AFLC and MAC.

(2) Provide the necessary training program to meet the above requirements and report the training schedule to AFSC, AFLC and MAC.

e. AFTEC will monitor the OT&E IAW AFR 80-14.

4. Schedules. Schedule will be as indicated in the AFSC/ASD Program Management Plan, ASD/SDX 74M-01, 4 March 1977.

1st Aircraft Delivery	FY 2/79
8th Aircraft Delivery	FY 2/80
PMRT Date	FY 2/80

5. Resources.

a. Cost Data.

(1) Engineering	$1,913,224	(P-1100)
(2) Testing	687,024	(P-1100)
(3) Data	4,587,525	(P-1100)
(4) Modification Kits (8 Gp A&B)	$10,347,059	(P-1100)

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EXHIBIT 22e

(5)	Technical Support	$ 119,567	(P-1100)
(6)	Initial Spares Investment	3,093,395	(P-1600)
(7)	Initial Spares Expense	1,283,334	(P-4921)
(8)	Support Equipment (Peculiar)	3,468,789	(P-1100)
(9)	Support Equipment (Common)	24,210	(P-1200)
(10)	Installation	2,347,341	(EEIC-540)
(11)	Technical Support	646,875	(EEIC-585)

b. Cost data in MPA, dated 4 Mar 77, titled, "Pave Low III", has been validated except as noted below:

	FY 78	FY 79	FY 80
Line 28. Installation Cost	293,457	1,467,060	586,824

6. Funding.

Total approved cost: $28,518,343

P-1100	EEIC-540	P-1200	P-1600	P-4921	EEIC-585	Total
$21,123,188	$2,347,341	$24,210	$3,093,395	$1,283,334	$646,875	$28,518,343

P-1100 funds will be issued to AFSC. All other funds will be issued to AFLC.

7. Procurement.

a. The contracting officer is responsible for awarding such procurements in compliance with the Armed Services Procurement Regulation and Air Force Supplements.

b. Procurement personnel should determine the feasibility of incorporating priced options for projected requirements of subsequent fiscal years.

c. The PMD does not constitute authority to obligate or expend funds, except as authorized in the appropriate PA/BA.

8. Reporting. A quarterly Management Report AF Form 111 will be submitted by AFSC to HQ USAF/RDQ/LGX/LGY. In addition, ASD/SDX will provide to the Weapon System Manager at WR-ALC with a report adequate for inclusion in the

GO-79 (all parts). WR-ALC will provide progress reporting in accordance with GO-79/K-21 procedures.

FOR THE CHIEF OF STAFF

ROBERT M. BOND, Brig Gen, USAF
Deputy Director of Operational Requirements
DCS/Research and Development

H. L. EVERETT
Associate Director
Dir of Maint, Engrg and Supply

EXHIBIT 22g

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[2] Department of Defense Directive 5000.1, Subj: Acquisition of Major Defense Systems, DDR&E, 13 July 1971.

[3] *DoD Architecture Framework*, Version 2.0, 28 May 2009.

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[10] Colucci, Frank, "Making Sense of Sandblaster," *Vertiflite*, *Summer 2009, Vol. 55, No. 2*.

[11] "Flying Blind in Iraq: U.S. Helicopters Navigate Real Desert Storms," *Popular Mechanics*, Oct 2006.